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The AMERICAN PHYSICS TEACHER

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On the Lack of Logic in the Literature of Physics

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ONE of the ideals that should be kept in mind in writing textbooks of physics is a logical presentation of the subject matter. In fact, since physical knowledge is ordinarily expressed in terms of mathematical symbolism, the ultimate aim, at least for advanced treatises, should be to put the entire subject on a postulational basis. This is, of course, only possible with those branches of physics which have reached a certain degree of finality, as, for example, classical mechanics and thermodynamics.[1] While it is obviously impossible to expect writers of elementary and intermediate texts to attempt such a presentation, it is nevertheless reasonable to require that elementary logical requirements should not be violated. It is true that in many branches of physics a completely logical presentation is impossible because of the incompleteness of our present knowledge; but it is equally true that in the treatment of subjects which have been clearly understood for a considerable time, textbook authors still are repeating the same illogicalities over and over again and are using a confusing terminology which would have been excusable only at a very much earlier stage of the development of physics.

It is the purpose of the present paper to point out certain defects in the logical framework of the presentations which are fairly common in present college texts. We shall then consider similar deficiencies found in advanced treatises. We have in mind primarily those errors of logic which have become current among physicists as a group and which have thus received the sanction of long and universal usage. Errors which are confined to individual authors or works will not be considered. It is further expressly not our intention to undertake a logical analysis of the foundations of physics, a much more difficult problem which has been considered, for example, by V. F. Lenzen[2] and by P. W. Bridgman.[3]

Clearly, it is impossible to treat any subject in a logical manner without an unequivocal and rational terminology. The necessity for reform in the terminology of physics has been urged by many, particularly by D. Roller,[4] whose point of view appears to be very similar to ours. It is not always possible, however, to separate questions that are purely terminological in character from those involving the logical structure of a given treatment, and we shall not attempt to do this in what follows. It is, further, our belief that the logical flaws which we have in mind are of wider scope than those which properly fall within the province of terminology alone.

One can reasonably make the following demands:

I. No more fundamental principles, postulates or laws should be stated than are necessary. (Newton, himself, laid down essentially this principle in the *Principia* under the heading "*Regulae Philosophandi*." In the less picturesque language of today, this is the demand of the non-redundancy of a set of postulates.)

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[1] An axiomatic treatment of these subjects will be found, for example, in Geiger and Scheel's *Handbuch der Physik* in chapters contributed, respectively, by Hamel and Landé.

[2] *The Nature of Physical Theory* (Wiley, 1931).

[3] *The Logic of Modern Physics* (Macmillan, 1927).

[4] *The Terminology of Physical Science* (Univ. of Okla. Press, 1929); "Physical Terminology," Sci. Mo. **31**, 543–547 (1930).

II. Whenever it is possible to give a precise statement of a law or definition in elementary terms, the precise statement should be used rather than one that is only approximately true.

III. When a term is defined for a special case it should not be used in a more general sense unless redefined.

IV. When a term is defined in one way it should not be used in a different sense anywhere in the book unless the new sense is specified. More generally, it is undesirable to have the same term used in two different senses in the scientific literature. This is a very common fault, and one that causes much trouble.

V. All terms unfamiliar to the student should be defined.

In the sequel we shall give illustrations of failure to observe these requirements, taken from current textbooks.

As an illustration of the failure to comply with requirement I, the usual treatment of the laws of motion may be cited. The majority of authors to this day give Newton's original formulation, although it is clear that Newton's first law is only a special case of the second, both being contained in the formula

$$\mathbf{F}=\frac{d}{dt}(m\mathbf{v}), \tag{1}$$

where the force **F** and velocity **v** are vectors.[5]

The laws of motion may be stated more economically as follows:

I. The time-rate of change of linear momentum of a body is proportional to the applied force, both force and momentum being regarded as vectors.

II. To every force acting on a body there exists a corresponding force that is equal in magnitude but opposite in direction, exerted by the body.[6]

The second statement is the equivalent of Newton's third law, which is usually stated, "Action and reaction are equal and oppositely directed." This form of statement is open to the objection that the terms *action* and *reaction* really refer to forces. This is a violation of our requirement V, since these terms are usually not defined, and it is always dangerous to let the student rely on his knowledge of the popular meaning of a term which has a precise and often entirely different technical meaning. Further, elsewhere in physics the term action has a definite meaning which is quite different from the one intended here.

It is, of course, quite proper to introduce the laws of motion by a discussion of a special and important case, that of motion under no forces (Newton's first law); but we think it should have no place in the formal statement of the laws. It is further desirable to indicate the frames of reference for which these laws are valid, for otherwise the statement of the laws of motion is incomplete.

An alternative treatment of the laws of motion, due to Mach,[5] is superior in many respects, although it is more abstract and therefore less suitable for elementary instruction. Nevertheless, we believe that it should be made the basis of the presentation of the subject of dynamics in intermediate and advanced texts, following, for instance, the example of Whittaker's *Analytical Dynamics*.

An illustration of a case where requirement II is not fulfilled is the following statement of Newton's second law, taken from a college textbook: "The net or effective force on a body is proportional jointly to the mass and the acceleration produced by this force." Since this statement is not true in the special theory of relativity, it lacks generality. Law I, given above, is no more difficult for the student and has the advantage of being more general.

As an example of a case where requirement III is not met, consider the term *electromotive force*. Quite apart from the fact that the use of the word *force* in this case is misleading, it is usual to define first the electromotive force of a cell as the difference of potential between the terminals when no current is flowing; the term is then used in discussing electromagnetic induction although the original definition is obviously no longer adequate.

Requirement IV, that no word or symbol should be used with more than one meaning, is violated especially frequently, and this invariably leads to confusion of thought. Mathematicians never use the same symbol with more than one meaning in any given discussion, for to do so would be to invite error. But language is full of words with two or more meanings or, in some cases, with a "continuous spectrum" of meanings. As long as this situation prevails language will be an imperfect instrument for the expression of thought. Many fallacious arguments have rested on nothing more than the use of the same word in two different senses. An exact science, such as physics, should be free from such flaws, and every technical word or term used should have a unique meaning. We shall give several illustrations of the violation of this principle.

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[5] The redundancy of Newton's first law was pointed out by E. Mach, *Science of Mechanics* (Open Court, ed. 4, 1919), p. 143.

[6] The second statement is taken from H. Crew, *General Physics* (Macmillan, 1929), p. 76.

(1) It is common to describe the *magnetic field* as the region of influence about a magnet and then to use the same term to designate **H**, the magnetic field strength. In this latter sense **H** is not a region but a vector point function. This dual meaning is confusing to students, although trained physicists hardly notice the ambiguity. Similar remarks apply to the term *electric field.*

(2) The word *induction* is used with two distinct meanings. The first is that designating the process of inducing something, as in the terms *electromagnetic induction* and *electrification by induction.* The second use of the word is in the terms *electric induction* and *magnetic induction*, to designate the vector quantities **D** and **B**. In this second case, the word induction denotes not a process but an entity, a fact that causes much confusion among beginners. We believe that the first use of the word is the more natural one and that *induction* should not be used in connection with the vectors **D** and **B**.

(3) The term *polarization* is used with the following distinct meanings: polarization of an electrolytic cell; polarization of a dielectric; polarization of light.

(4) The term *adiabatic* has two distinct meanings, one in thermodynamics and another in quantum theory.

These four examples bring out especially clearly the need for a rational and standardized terminology. It has been long recognized, chiefly due to the work of modern logicians such as Peano and Russell, and more recently, Carnap, that our language is not adapted for the very precise formulation of abstract ideas necessary in the exact sciences; logic and mathematics have been the first to feel this inadequacy of language, and as a result are becoming more and more dependent on the use of symbols in cases where formerly ordinary language was thought to suffice. While physics is as yet far removed from this stage, we should at least eliminate the ambiguities arising from the use of the same terms in several senses, even if it is necessary to coin new words. Of course, for a fundamental reform of terminology a collective and organized effort is required; such a task would be probably within the province of the Commission on Symbols, Units and Nomenclature; if not, it might be desirable to consider the appointment of an international committee to deal with radical changes in terminology.

An example of the failure to meet requirement V is the use of the terms *ground* and *short circuit* without defining them. We have never seen any definitions of these terms in textbooks of physics or electrical engineering. Most students probably learn their meanings gradually by experience. These terms are defined in dictionaries, but definitions of technical terms in dictionaries are frequently unsatisfactory. For example, *Webster's New International Dictionary* (ed. 2, unabridged) gives:

"Ground: To connect with the ground (of potential zero) so as to make the earth a part of an electrical circuit."

Obviously this definition does not cover all cases in which the term is used; for example, the ground connection on an automobile is entirely insulated from the earth by the automobile tires. Again,

"Short circuit: A circuit, purposely or accidentally made, through a small resistance, especially one which acts as a shunt to one of comparatively large resistance."

Although this definition cannot be said to be incorrect, it does not appear to bring out the particular shade of meaning ordinarily wanted. It does not distinguish between a *shunt* and a *short circuit*, or emphasize the fact that the term short circuit is ordinarily used to designate a situation which is accidental. Even when the short circuit is made deliberately the term carries with it the implication that the mode of procedure is inexact and haphazard, while a shunt is more likely to be of known resistance calculated to accomplish a certain purpose. Altogether, the term *short circuit* is vague and often is a source of difficulty to beginners.

Instances of this kind could easily be multiplied, but possibly enough has been said to support the contention that a not inconsiderable part of the difficulties encountered by the beginner in physics must be laid at the door of textbook writers whose presentations are illogical at important points and whose terminology is often ambiguous.

These flaws in elementary logic, although not confined to elementary texts, are found less frequently in advanced works. However, new and equally serious logical deficiencies appear in the advanced treatises. We shall begin by considering a violation of our requirement IV, the use of a term in two distinct senses. The term *ether* has been used in one sense by the classical physicists and in another by some relativists. In prerelativity physics it meant a quasi-material medium which was supposed to fill all space. Such an ether is inconsistent with the theory of relativity, but some leading relativists have continued to use this term with a new meaning:[7] the totality of physical properties of space devoid of matter; namely, the metrical tensor $g_{\mu\nu}$, the electromagnetic field tensor $F_{\mu\nu}$, and the energy-momentum tensor $T_{\mu\nu}$. The ether as thus conceived is not a substance, and other relativists, as for instance Frenkel, include these physical properties in the term *empty space*. As a consequence, disputes arise concerning the existence of the ether that are purely terminological in character, a circumstance which is not always realized by the disputants. Thus, Einstein has been quoted as believing in the ether by physicists trying to make out a case for the old-fashioned ether, whereas Einstein had used the word in the newer sense. It is clear that this use of a single term with two meanings makes for confusion of thought; in a mathematical or logical discussion it would be considered not a defect, but simply an error, and a similar attitude in physics should be encouraged. The term *ether* should be discarded on the grounds that it represents a concept which is no longer useful; the modern sense of this term is accurately rendered by the term *empty space*.

In general the most common defects in the advanced literature can be divided into two classes:

1. Failure to state the simplification of the physical situation that has been made in order to obtain a mathematical problem which can be solved without too great difficulty; or, more generally, failure to state the physical assumptions or postulates used.
2. Lack of rigor in the subsequent mathematical development, not explicitly pointed out by the writer; in particular, the habit of making an approximation without justifying it or, alternatively, stating that the approximation has not been justified but that the author is using it with the hope that it will be satisfactory (which frequently means a result in agreement with experiment).

Although there seem to be a number of capable physicists who consider these defects inessential, there are others who, like the late P. Ehrenfest, are never satisfied until everything is crystal clear.

So-called "obvious" and unstated assumptions are often stumbling blocks in the path of progress. One reason for this is that they are frequently unrecognized preconceptions and would be recognized as such once they are clearly stated and subjected to a critical analysis. The origin of the special theory of relativity affords an illustration. Before 1905 practically all physicists tacitly assumed that length was an inherent property of a body, quite independent of the state of motion of the coordinate system in which it was measured. However, Einstein's profound logical analysis of space and time measurements resulted in the denial of this preconception and the establishment of the special theory of relativity. Yet, if anyone writing a book on mechanics on a postulational basis before Einstein's researches had stated as one of the fundamental postulates that "The dimensions of objects are independent of the state of motion of the coordinate system in which they are measured," it would have been very probably looked upon as a pedantic performance. Yet this would have been a step forward, for once a postulate has been stated, the possibility of its denial occurs to a critical mind. This is, in fact, one of the advantages of the postulational method. The work of Lenzen,[2] Bridgman,[3] H. Reichenbach,[8] and others shows that all our physical theories contain a large number of such tacit assumptions or "unconscious hypotheses," as they were termed by H. Poincaré. Therefore, to put our existing body of knowledge into its best possible logical form is an important aid to research.

We are not, of course, attempting to argue that in a science which will probably always remain incomplete, it shall ever be possible to avoid logical jumps or uncertain assumptions, but are merely urging that all such weak points should be clearly pointed out. Otherwise, in many instances, one gets the impression that something has been rigorously deduced from a given set of assumptions when in fact such is not the case.

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[7] W. Pauli, *Relativitätstheorie* (Teubner, 1921), p. 584.

[8] *Philosophie der Raum-Zeit Lehre* (deGruyter, 1928).

Another example of the failure to state all the assumptions involved occurs in one of the usual derivations of the formula $\mathbf{E}^2/8\pi$ for the density of electrostatic energy in space due to the electric field strength **E**. Consider, for example, the derivation in Abraham-Becker, *The Classical Theory of Electricity and Magnetism*, page 83. The author obtains the well-known expression for the energy of the electrostatic field due to a continuous distribution of charges by the use of Green's theorem without stating that the result is valid only if the product of the potential and the normal component of the electric field strength vanishes in a suitable manner over the infinite bounding surface—a condition that can be satisfied only if the charges are localized in a finite region of space. Thus the result might conceivably be invalid in certain cosmological problems. It is true that Frenkel in his *Lehrbuch der Elektrodynamik* does state the conditions that must be imposed in order to carry through this derivation, but we believe that this is contrary to the procedure in most treatises on electrodynamics; Green's theorem is usually applied in this and similar cases without an explicit statement concerning the conditions at infinity necessary for the validity of the result.

Next consider the treatment of the connection between entropy and probability originally proposed by Boltzmann. It is usual in books on statistical mechanics to derive the formula

$$S = k \log W \qquad (2)$$

by the following simple argument. Suppose that we have two physical systems which we shall designate by subscripts *1* and *2*. Now let us regard the two systems as one. Then, according to the laws of probability, the thermodynamic probability W for the combined system is W_1W_2, but the entropy S for the combined system must be S_1+S_2. This is possible in general only if Eq. (2) holds. There are, however, several serious flaws in this argument, which are discussed in detail by R. H. Fowler;[9] the most damaging flaw is the confusion between thermodynamic and mathematical probability, and it alone is sufficient to invalidate the entire argument. Yet this fallacious account is repeated without criticism in many recent advanced texts.

In conclusion, it may not be out of place to make a few remarks of a more general nature which would be applicable primarily to the most advanced treatises and especially to those dealing with recent developments. In an inductive science such as physics, the theoretical structure of which is continually developing, an important function of a good logical treatment is to bring out the relationship between theory and fact in a proper manner. The tentative character of existing theory should be given the same emphasis as its successes, and the limits within which the theory is valid should be explicitly stated. Furthermore, the entire approach should be critical in character and mention should be made throughout of the unsolved problems in the domain considered, so that the student may get a glimpse of the borderland between the known and the unknown and thereby be stimulated to think and investigate for himself. The majority of the existing advanced treatises on physics do not fulfil these desiderata, and are written in such a manner as to create the impression that practically every problem has been solved. Of course, there are books that realize these aims to a considerable degree; good examples are Frenkel's *Lehrbuch der Elektrodynamik* and Tolman's *Relativity, Thermodynamics and Cosmology*.

The authors gratefully acknowledge interesting discussions with Professor T. D. Cope, Dr. F. G. Fender, and Mr. H. A. Finkelstein.

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[9] *Statistical Mechanics* (Cambridge Univ. Press, 1929) p. 137.

I believe that I am not overstating the truth when I say that half the time occupied by clerks and draftsmen in engineers' and surveyors' offices . . . is work entailed upon them by the present farrago of weights and measures.—LORD KELVIN.

The Two-Year Science Program in Columbia College

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A NEW science program consisting of a two-year integrated sequence in the physical and biological sciences has been in operation in Columbia College since 1934. This program is intended primarily for students who do not expect to major in a natural science. The faculty has felt that there is need for a unified course, given by the various science departments cooperatively; that the traditional one year of a specific science and of mathematics does not provide sufficient opportunity for an acquaintance with, and understanding of, the main facts and principles, the methods, the thought, and the dominant trends of modern science. From cultural as well as so-called "practical" considerations, every college graduate of today should have a background that includes knowledge of the achievements and applications of the physical and biological sciences, especially in view of the increasing importance of these sciences in the political, social and economic system.

The course has so far been offered as an optional method of satisfying the science requirements for the A.B. degree, but student response indicates that a large number prefer this program. Formerly, comparatively few students chose the traditional physics course as one of the components to satisfy science requirements.

Development of the course

After considerable discussion within the faculty, a committee representing the various science departments was appointed by Dean Hawkes to discuss possible types of cooperative programs. While there was difference of opinion, all members of the committee felt so strongly the need for some such undertaking that it was eventually found possible to agree on a tentative general outline. The committee was then enlarged to include those who were to be responsible for the actual instruction, to give them full opportunity to aid in the construction. The plan adopted was frankly a compromise. From the standpoint of unity, it would be desirable to have one professor in charge of the entire program, but it was difficult to conceive of any one man sufficiently competent in all the sciences. The other extreme, a "vaudeville" course with a large number of "stars" in every field paraded before the students, had been found by experience in various institutions to be seriously lacking in unity and perhaps on that account generally ineffective. The plan of having four professors, one for each semester, seemed a reasonable compromise. It assured competence and a reasonable degree of unity and continuity.

Physics seemed basic to the other sciences, and was selected as the chief subject matter for the first semester. Unity in such a course does not just happen; constant effort is required to ensure it. Continual discussion meetings and other efforts of the interdepartmental committee have been necessary. Each instructor has had to be willing to sacrifice the foibles of his particular science for the good of the plan as a whole; this has been especially true of the instruction in the first semester of the course. The efforts to prevent the program from degenerating into four isolated one-semester courses have now made it possible for a complete consideration of the course and its unity to be undertaken by a committee, on the basis of the past three years' experience.

General organization

The form of general administrative organization for such an undertaking naturally will differ considerably among institutions. Since it is desirable to emphasize this as a *unified* science

Table I. *General organization of the course.*

Semester	Course No.	Description
1	Sci. A-1	*Matter, Energy, and Radiation.* Largely physics, in charge of a physicist.
2	Sci. A-2	*Chemical Changes in Matter.* Largely chemistry, in charge of a chemist.
3	Sci. B-1	*The Earth—Its Origin and Physical History.* Largely astronomy and geology, in charge of a geologist, and in cooperation with the astronomy department.
4	Sci. B-2	*Transformations of Matter and Energy in Living Organisms.* Largely biology, in charge of a biologist.

course, we insist that the semester courses be called *Science A-1*, etc., as shown in Table I, and not physics, chemistry, etc. Careful consideration of the problem of organization of material and the overlapping of various phases in some of the fields, as in physics and chemistry, led to the decision that for this group we should reorganize the subject matter and not be bound by any traditional mode of presentation.

The time allotted for this program, five hours per week for four semesters, is large compared to that in many institutions. But we have felt that this was the minimum time in which we could accomplish our purpose satisfactorily, and that less than this time would only justify the unfortunate connotations of the term "survey." Three hours per week are spent in general classroom work, and used as best suits the material under discussion at the time. Two hours per week are given over to laboratory work, since it was felt by all that no real understanding of science could result unless the student had an opportunity to work with his own hands in the laboratory.

Even with the generous time available, it is clear that if shallow superficiality and a mere cataloging of facts are to be avoided, we must continually focus attention on the fundamental principles and keep the important phases clearly outlined, thus opening up the vital questions in the various fields. Much material has been deliberately omitted in order to concentrate more effectively on the fundamental topics and drive home the essential ideas.

Organization of Science A-1

In order to emphasize the unity and relationships of physics, Matter, Energy and Radiation have been selected as the fundamental sections, thus cutting across traditional lines where mechanics, sound, heat, light, electricity and magnetism are treated as isolated compartments with a section on modern physics added as an afterthought. The atomic nature of matter, and the developments and implications of modern physics have been woven into the structure wherever they logically enter it. The general organization of the material of Science A-1 is indicated in the following brief outline. The main topics for the other three semesters are given more briefly to show something of the nature of the unified program.

Semester 1, Science A-1: Matter, Energy, and Radiation

Introduction
  What do we mean by science?
  Science and civilization
  Historical development; importance of experimentation
Matter
  Three states of matter
  Physical properties
  Physical and chemical transformations
  Atomic nature of matter
Energy
  Concept of energy
  Statics, dynamics, potential and kinetic energy
  Various forms of energy and methods of measurement: mechanical, thermal, electrical, wave energy, etc.
  Energy transformations, the basis of material civilization
  Conservation of energy
  Particle nature of matter; atomic structure
  Kinetic theory; gases, liquids and solids; gas laws
  Statistical nature of kinetic theory; role of theory and experiment
Radiation
  The electron
  Electrical circuits; conduction in gases; thermionic emission, vacuum tubes
  Temperature radiation; the quantum; photoelectricity
  Spectra; atomic structure; quantum theory
  X-rays
  Electromagnetic spectrum; particles and waves
  Nuclear physics: radioactivity; nuclear transformations
  Equivalence of matter and energy

Semester 2, Science A-2: Chemical Changes in Matter

  Elements, compounds and mixtures
  Solutions
  Chemical equilibrium
  Some groups of the elements
  Metals
  Carbon compounds; organic chemistry
  Foods

Semester 3, Science B-1: The Earth, its Origin and Physical History

Astronomy
  Solar system and universe
  Earth as a planet
Earth as a geologic body
  Historical development
  Various geologic ages
  Geologic transformations
  Advent of Man; human culture

Semester 4, Science B-2: Transformations of Matter and Energy in Living Organisms

  Living matter
  Sources of materials and energy
  Utilization of energy in maintenance
  Utilization of energy in advancing processes: growth, reproduction, heredity, and evolution

A syllabus has been written for each of the four semesters.[1] These syllabi are largely in outline form, and are intended to serve not as texts, but rather as guides to the students' thinking, focusing their attention on major topics, emphasizing important phases of the fields, and opening up the important questions. The syllabus keeps the student from being lost in a mass of details where he might not see the "woods for the trees."

Considering the first semester specifically, we have not wanted the student to "learn" a single textbook. No available textbook fits either the group or this particular organization of material and therefore the students have been encouraged to choose any one or more of the following as a principal reference text. During a given term, however, the text indicated has been especially emphasized: Loeb and Adams, *Development of Physical Thought* (1934–35), Lemon, *From Galileo to Cosmic Rays* (1935–36), Knowlton, *A Textbook of Physics* (1936–37). None of these texts is designed of course for our particular plan. We have been reluctant to write a text specifically for this group, and thus commit ourselves to a permanent form, before we have experimented and varied enough factors to feel certain that a satisfactory form has been developed.

Science reading room.—Such a course should encourage the student to read widely and hence a list of "essential and suggested readings" is placed at the end of each week's section of the syllabus. These are purposely not assigned as "required readings." In the main library a special reading room has been set aside for Science A-B students. A free atmosphere without too much supervision is attempted in order to encourage "browsing." Selected books ranging from popular versions, biographies, and histories, up to more advanced texts have been provided so that the student may go as far as he likes along any line which interests him. A number of periodicals such as *Science Service News Letter*, *Science*, *Scientific American*, *Nature*, etc. are included. Naturally not all students really take advantage of their opportunities for wide reading, but the number who do so is very encouraging.

Class meetings; discussion groups. Three one-hour periods per week are devoted to general class meetings and discussion-quiz groups. Two or more of these meetings per week are devoted largely to demonstration lectures. In view of the short time available all illustrative material and demonstrations have to be chosen carefully from the standpoint of their value in bringing out the important points in the syllabus. Demonstrations that clearly illustrate the subject matter and at the same time have strong appeal to the attention are particularly useful. Experiments that are merely spectacular of course miss the point entirely. One professor is in charge of the work of a given semester, but where supplementary lectures by men unusually qualified in special fields fit into the continuity, they are often found desirable. Motion pictures have been found useful as supplements to teaching, but not as substitutes. Whenever a real demonstration with actual apparatus can be performed, it always seems to be more satisfactory. In some cases, however, the subject matter is especially suited to motion picture technic, and dynamical material can be shown with exceptional effectiveness through this medium.

When the group was small, considerable discussion within the class meeting was encouraged. When the class grew to 150 students, the amount of such discussion of important questions and problems had to be limited. This year special discussion sections of about 20 students were held once every other week, and the response of the students and increased understanding were so evident that next year it is planned to have discussion sections weekly. A 10-min. quiz is given at the discussion meetings, with the remainder of time devoted to discussion of difficulties, working of problems, etc. These small sections present a staff problem in that a large number of instructors are needed for one semester only. However, while in a college the instructors will be primarily physicists or chemists, it should be possible to find men with a good training in both fields so that they are able to handle discussion or laboratory sections throughout the first year of the course. Such joint instructors serve to tie together the two semesters, a function exceptionally important in an organization of this type.

Division of students.—A wide spread of ability and interest in the sciences naturally exists among the students in this course. Some 50–60 percent have had physics, 50–60 percent chemistry, and 55–65 percent some type of biology in secondary school. A large fraction thus already has some background in the sciences. On the other hand, these students are mainly non-science majors who may wish to be anything from artists to economists. Some have had no previous acquaintance with the sciences and apparently no ability for them. Many have deliberately avoided the sciences until faced with the necessity of fulfilling the two-year science requirement in the college. Fortunately physics has so much intrinsically interesting material and so many ramifications into every field, that these students usually can be "sold" physics. We have found none completely devoid of interest, and some of those who have heretofore avoided the sciences eventually become some of the best students.

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[1] Columbia University Press.

With such an unusually wide student range, however, the presentation of material in the class meetings, discussion groups and laboratories is seriously affected. In the general class meetings the poor background of many is met by careful attention to fundamentals, and at the same time the needs of the upper group are recognized by going as far as possible beyond secondary school physics. The course is so organized that it is distinctly not secondary school physics or even college physics, and the students soon understand this clearly. Because of this, and because the two-year sequence is to be considered as a whole, we have not as yet excused students from any semester. However, in the future, in exceptional cases, the passing of a satisfactory achievement test may excuse a student from a given semester. It has been said by some that the continued development of secondary school "survey" courses would eliminate the necessity for a similar science program in the colleges. From our experience this is definitely not the case. The science background in secondary school can serve as a basis for placing the college science program on a higher and more satisfactory level. It is difficult to see how a "survey" course in the average secondary school could be given on a high enough plane to be adequate on the college level.

For the present the problem of wide student range is being met by dividing the discussion groups on the basis of background and ability, and in the future, the laboratory sections will be similarly divided. Initially, this placement is made by considering the student's score in the *Thorndike Intelligence Test*, a mathematics placement test, and a science placement test. Many who place in the upper group in these tests have had no secondary school physics. Furthermore, our final records for the past three years show only a small shift downwards in the median performance of men new in physics as compared to those who have had secondary school physics. An initial placement based solely on the fact of having had secondary school physics would have been unsatisfactory. Previous work in physics does not necessarily mean excellence in Science A-1. In fact one must be very careful lest such men be lulled into a false sense of security at first because they have heard some of the concepts before. Those who have not had physics previously often make up for it by greater effort and intelligence. A number of these men in the upper group decide during the course to change over into a specific science as a profession.

As the semester progresses, student performance affords a means of adjusting placements. While such methods of placement are admittedly inaccurate, they serve at least as some sort of basis for dividing the students into more homogeneous groups—of about 20 for discussion and 10 for laboratory. The upper groups can then be given an opportunity to go more thoroughly and further into the material, while the lower groups can be given the sort of experience they need, and can do the best possible job without handicapping both themselves and others.

Quizzes.—Weekly quizzes of 10–15 min. duration are essential, both to keep the men "on their toes" and to provide them with some measure of their own understanding and achievement. Objective type, multiple-choice questions have numerous advantages. Properly phrased, they make it possible to cover a wide range of material, and permit reasoning, factual, and quantitative problem questions to be given. We have regarded reasoning and accuracy of ideas important and have avoided overemphasis of small details. While excessive concentration on problems is not desirable, one fairly substantial quantitative problem and, occasionally, an essay type question have usually been included with the objective questions. Because of the large number of students asking for quantitative applications we have suggested many such problems, whose solution is optional. We want the students to realize that we have no illusions about the accuracy of quizzes in measuring knowledge; but that, since some attempt at measurement is necessary, quizzes are used and may be regarded as similar to physical measurements.

The distribution of numerical grades with approximate letter grades is plotted on the board the day following a quiz so that a student may know his relative standing. This permits him to understand clearly when he is in the danger region, and also serves to remove the unfortunate misconception often carried over from secondary school that some arbitrary mark such as *60* is always "passing," or that the man who gets *92* knows definitely more than the man who gets *91*. The fact that so many phenomena, from human performances to the behavior of molecules in a gas or to the disintegration of radioactive atoms, follow distribution curves of the same general form, and that statistical laws are involved in nearly everything with which we come in contact is thus made clear.

The laboratory.—The experimental basis is so important in all science that the student must have an opportunity to experiment for himself if he is to appreciate thoroughly how science grows and develops. Such first-hand experience in the methods and technics of the various fields is essential to an understanding of science and its accomplishments. Conventional laboratory courses have undoubtedly been far from inspiring to many students; yet there seemed to be no reason why the laboratory, if properly dealt with, should not be the most interesting part of the work and a most effective teaching aid. Consequently we have deliberately undertaken a fresh start on the laboratory question. The class is divided into as small sections as feasible, usually 10–12 students. Our laboratory space is arranged as a series of small rooms, thus facilitating the handling of such groups. The group, under the guidance of an instructor, sets out to investigate the phenomena under study, sometimes as a group, sometimes in small sub-groups, and sometimes individually. In each laboratory period an attempt is made to cover two significant experiments; some are quantitative and some qualitative. By setting up successive experiments in two or three rooms, many sections may be handled with a minimum of equipment, since as one group moves on to another room, the next section takes its place.

Experiments have to be chosen on the basis both of fundamental importance and of intrinsic interest. Wherever the choice lies between two experiments illustrating the basic phenomena equally well, the one that has the most telling vital interest is selected. Each experiment is developed so that its fundamental points are as clear-cut and even as spectacular as possible. Large-scale apparatus rather than toy models is desirable, particularly for group experiments. Large pulleys should be used to lift weights of 200–300 lbwt. or more; several students are then required to lift the load so there is full participation and an appreciable expenditure of physical energy. In measuring the mechanical equivalent of heat, a large apparatus in which "real" work must be done by hand, the students taking turns, impresses the ideas clearly. In studying the conversion of electrical to mechanical energy, a 2- to 5-hp. motor makes the test more "practical." A group experiment is particularly successful when each student has some part in it and when the students shift around, each taking his turn at some function. With competent instructors who can work with the students and tactfully lead them to formulate their own attack on a problem, such group experiments work remarkably well. Better apparatus can be afforded, and more experiments can be performed since fewer sets of apparatus are needed. We wish the student to obtain as wide a view of experimental physics as possible, and thus less emphasis is placed on precision or quantitative measurements. The group method just described seems to meet this need more satisfactorily than individual experiments.

The laboratory sections in the future will be arranged on the basis of ability, so that the better students can go much deeper into experiments or undertake additional ones. No set limit is placed on the number of experiments or on the amount of time spent on a given experiment. If one section is strongly interested in a certain experiment, it may omit some other one entirely. A good deal of opportunity for discussion of the experiments, between students, and between instructors and students naturally presents itself. Frequent conferences with the laboratory instructor outside of the laboratory period provide further individual attention.

Each student has a special notebook in which he writes down the essential ideas, tabulates the data, and makes schematic drawings of the apparatus, etc., during the laboratory period. Where possible, results are plotted roughly during the experiments so that the general trend of the measurements is clear. In this same notebook the student later summarizes the purpose, essential procedure and theory of the experiment, arranges data, computes results when this has not been completed in the laboratory period, plots curves where desirable, and formulates the fundamental conclusions in as concise a form as possible. The notebook is handed in within 5 days and the instructor returns it at the beginning of the next laboratory period with appropriate suggestions. These reports are not highly formalized but rather are considered as an opportunity for the student to crystallize his ideas about the phenomena investigated. Naturally some students wish to supplement their reports by further reading or investigation.

This method of handling the laboratory problem has been found quite satisfactory and more suited to the aims of the course than the traditional method. Student interest and enthusiasm is maintained on a much higher level, and, while the instructors probably must exert more effort and care than ordinarily, the results seem decidedly worth it. In the end, accomplishments compare surprisingly well with those of regular physics students. Students uniformly agree that the laboratory is one of the best parts of the course.

Extra-laboratory work.—Special field trips offer excellent opportunities to enlarge the scope of the student's experience. They should not be undertaken merely for the sake of making trips, but selected and planned so as to make a real contribution.

During the opening period, when the historical development of astronomy is being used as an example of the way in which all sciences begin, live and grow, a special program has been arranged at the Hayden Planetarium of the American Museum of Natural History. A part of the first laboratory period has been spent in the Rutherfurd Observatory, with an optional visit to the observatory at night. Thus a first-hand picture of astronomy is obtained. Of course, astronomy is dealt with much more thoroughly the third semester. A trip to a power plant and a visit to the mechanical engineering laboratories of the School of Engineering has usually been made to study various types of heat engines and energy transformations. An optional visit to the Museum of Science and Industry is suggested.

This fall, in cooperation with the parallel two-year course in the social sciences (*Contemporary Civilization A-B*), the program of special trips outside of regular hours will be considerably enlarged. The Metropolitan area offers an unusually wide range of opportunities for study, varying from purely scientific projects, applied science developments, and industries, to those institutions in which economic and sociological aspects are particularly evident. The Science A-1 group will be particularly interested in trips to such places as the New York Edison Co., the Westinghouse Co., RCA, the New York Steam Co., the A. T. and T. Co., the Coal and Water-Gas Plants, the Western Union Co., the Holland tunnel, and the Ford assembly plant.

Since students ought to have a real appreciation of the spirit of pure science and the meaning of experimental research, visits to research and experimental laboratories where work is in progress in subjects under discussion in the course have considerable value when properly chosen and handled. Visits to researches dealing with the solid state, crystal structure, low temperatures, molecular beams, magnetic or electrical measurements, spectroscopy, high voltages and nuclear physics have both educational and stimulative value. The subjects studied cease to be cut and dried material in textbooks. It becomes evident that physics is living and growing, and that we are only beginning to scratch the surface in our understanding of nature; a good deal of perspective and some appreciation of the tremendous amount of intensive and patient labor behind results and discoveries is gained. In the attainment of some understanding of what science is and what it is doing, certainly the research laboratories cannot be omitted.

Special work.—In any course, whether elementary or advanced, one can go only a short way down the various avenues of thought in a field. The opportunity is open, however, to go as far as the student's initiative and interest will carry him. The Science Reading Room provides one opportunity for those who wish to learn more about some aspect of their work. Students in the better sections have been encouraged to follow up their interest in some phase of physics and write a term paper. Usually about one-third of the class has been interested enough to write one. The papers range from mere attempts to some that are remarkably good. Often students go to great lengths to gather their information. One man who was interested in steam power plants, after looking up the literature and visiting several museums, went to a number of power plants and, finally, to a factory where turbines were being built.

To encourage those who want to go further into experimental work, we have provided such an opportunity for a limited number of capable and interested men. The regular laboratory apparatus is available for work under guidance. Special projects such as studying crystal structure, working with high speed centrifuges, testing motors, building amplifiers or radios, more advanced work with the cathode ray oscillograph, etc. have been permitted where the background and interest of the students warranted it. Although such special projects could not be handled on any large scale, they are particularly desirable for the abler students.

The operation of the program

The three years of experience with the Science A-B unified program have confirmed our original belief that such a cooperative undertaking could be successfully administered. It seems to be accomplishing the fundamental purposes set forth at the beginning. While much further improvement will doubtless be made, no serious defects have appeared. This definitely is not a "snap" course; the scope and amount of work involved are such that it requires more intensive effort than most courses. Nevertheless, general student sentiment definitely indicates that this two-year sequence represents a more satisfactory arrangement for those men who do not intend to use the sciences professionally, than the older methods of fulfilling the science requirements. This enthusiasm has been reflected in rapidly increased registration and in the excellent attitude toward the course.

Each year a number of students of real ability find through this course that their real interest is in some field of science. Certainly the science departments do not want an influx of mediocre students into advanced work, but if the course leads a few really good men into science, it has served an additional worthwhile purpose. Students who stop at some stage to specialize in a particular science need not complete their two-year sequence since their science requirements are fully met in their new schedule by the time they graduate. Science A-B students are admitted into more advanced courses on the basis of individual merit.

As far as the physics department is concerned, virtually all of the students in Science A-1 are men who heretofore would never have had any contacts with physics. Before this program was inaugurated nearly all of them would have chosen some supposedly less painful method of satisfying the degree requirements than physics or chemistry. Most elementary science courses, rather than being depleted, have either held or increased their enrolments, with increases in advanced courses also. With the exception of physics, the departments involved in the program have dropped the so-called "A" courses (2 semesters, 4 hours each), formerly given for those who have not had introductory courses in secondary school.

The Science A-1 course has been largely an experiment, and as time has passed we have naturally tried different approaches and made changes where desirable. Indeed, if it ever became frozen into a stereotyped form, it would lose much of its life and vitality. The experience in Columbia College with this cooperative undertaking may not be directly applicable to other institutions where differences in administrative and departmental problems, curriculum organization, and physical plant exist, but we trust that some parts of it will be interesting to those who are experimenting with or considering such courses. Our experience has firmly convinced us that such a course is a considerable improvement over the traditional method of satisfying science requirements for the Bachelor's degree. Properly evolved on a high enough plane, it offers unusual possibilities for the great mass of the students in our colleges who are not going primarily into science, but who previously had little or no contact with it. Thus it represents a new opportunity for raising the level of appreciation and understanding of the sciences in general and of physics in particular.

A Model of Ferromagnetic Action

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THE kind of model of a ferromagnetic material which J. A. Ewing[1] built four decades ago, has since been made in less elaborate form for many lecture demonstrations in ferromagnetism, and has proved to be valuable in teaching this difficult subject. On the other hand, the theory of ferromagnetism has changed considerably since 1900 and Ewing's interpretation of his model is not entirely consistent with modern ideas. But the model behaves in striking accord with recent theory if we imagine each pivoted magnet to correspond, not to an atom as Ewing proposed, but to a large group of atoms, a "domain" as P. Weiss[2] used the term. Thus the same physical model can be shown first to illustrate Ewing's theory, and again to illustrate the domain theory and the manner in which the spontaneous magnetization of a domain, directed along any one of the axes of the "crystal" when no field is applied, is rotated suddenly from one stable position to another as an applied field increases, and finally is pulled into parallelism with the field when the field is sufficiently intense.

The construction of the model and the method of applying the field will be described, and then its significance for both the Ewing and the domain theories and the extent to which it corresponds in properties to a real magnetic material will be discussed.

Construction

The model that we have used is composed of a two-dimensional array of magnets and a pair of coils and associated apparatus for producing a magnetic field. It is so constructed that it can be used with a lantern designed for opaque projection. The arrangement of the magnets can easily be seen in Figs. 2 and 3. The surface of the model may be divided into two parts by a line joining two opposite corners, so that in each part the magnets are in a square lattice but the two lattices are at an angle of 45° with each other.

The magnets are mounted upon needles which in turn are mounted in a solid brass block and the entire assembly is immersed in a pan containing spindle oil. The brass plate actually used was 0.63 cm thick and 16.5 cm square. Upon it the pattern for the magnets was laid out with 1.9 cm between the magnet centers. The holes were drilled 0.48 cm deep and just slightly larger in diameter than the needles. The latter were sewing needles that had been broken off 1.1 cm from the point. The brass plate was heated and the needles were set in the holes with paraffin.

The magnets were obtained from magnetic compasses purchased for 10 cts. each and were cut from the original length of 3.6 cm to about 1.7 cm. After assembly, the lengths of the individual magnets were adjusted so that no two magnets could touch. We found it necessary to remagnetize the magnets so that each would have about the same strength and the dark halves would all have the same polarity.

This assembly was put in a copper pan 2 cm deep which was filled to a height just above the magnets with light spindle oil (office machine oil) to damp the vibration of the magnets. In order to brighten the image obtained with the projection lantern a thin chromium-plated brass sheet, with holes drilled to let the needles pass through, was laid over the lower brass plate.

The magnetic field necessary to operate the model is obtained from electric currents in two mutually perpendicular one-layer coils of No. 26 double-silk-covered copper wire wound on a block of wood 16.5 cm square and 5 cm thick. The assembly of magnets is placed on top of these coils and the magnetic field outside the coils acts on the magnets. The circuits for controlling the current in the two coils are mechanically interconnected so that when the current in one coil is changed the current in the other coil also changes. In this way the magnitude of the magnetic field can be kept constant while the direction of the field changes. If only one coil is used the magnitude of the field can be changed and its direction reversed.

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[1] *Magnetic Induction in Iron and Other Metals*, ed. 3, (Electrician Co., London, 1900).

[2] J. de Physique [4] **6**, 661–690 (1907); P. Weiss and G. Foëx, *Le Magnétisme* (Colin, Paris, 1926), Chap. X.

A diagram of the circuit is shown in Fig. 1.

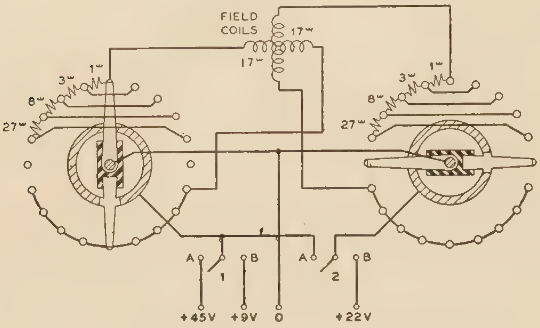

Fig. 1. Circuit for control of the magnetic field.

The rotating switches were made from General Radio 20-point panels with an extra contact ring added. The two ends of the contactor spring were insulated from each other and bent to make contact, one with the center ring and the other with the extra, added ring. The two panels were mounted with their backs together and the center shafts were connected so that the contactors on the two panels moved together. These contact arms were set perpendicularly so that when the current in one coil is a maximum the current in the other coil is zero. The values of the resistances were so chosen that the vector sum of the two magnetic fields is approximately constant in magnitude but changes in direction for the different positions of the contactor. These values depend upon the resistance of the coils but can easily be calculated; those used by the authors are shown in Fig. 1. The magnitude of the field is changed by operating one or both of the switches shown. For a rotating high field both switches are set in position *A*. For a rotating low field switch *1* is thrown to position *B* and switch *2* to position *A*. For an alternating field switch *1* is opened and switch *2* thrown to position *B*. For no field switch *1* is opened and switch *2* is opened or thrown to position *A*.

Fig. 2 shows a photograph of the apparatus. In Fig. 3, for (*a*), a strong field was applied from left to right. For (*b*), this field was reduced to zero. For (*c*) a small field was applied in the direction opposite to the original high field; note that all of the magnets pointing down and to the right in (*b*), and a few of those pointing straight to the right, have now changed orientation, but that practically all of them point to nearest neighbors. For (*d*) the group was mixed up by waving over it a permanent magnet.

A model of this kind might be constructed more easily if it were not intended to be used with a projection lantern. The flat surfaces of the coils could then be made larger than the lattice of magnets, so that a more uniform field would exist over the area of the model. The circuit could also be much simplified by using only one coil and an ordinary slide-wire potential divider and reversing switch. The effect of a rotating field might then be demonstrated by rotating the model with respect to the magnetizing coil.

Demonstration of Ewing's theory

First let the model represent a ferromagnetic material, each pivoted magnet corresponding to an atom with a fixed moment. The model then exhibits the following phenomena: the magnetization curve with its three distinct portions, the hysteresis loop with its attendant energy loss and remanence and coercive force, rotational hysteresis loss disappearing for high rotational field strengths, the influence of vibration, and the existence of time lag and of accommodation with repeated reversals of the field. The effects of stress may also be inferred from the model; thus a unidirectional stress may be expected to have a large effect relative to a hydrostatic stress, and one may even construct a model to illustrate two-dimensional tension or shear, as Ewing did by arranging pivots on a jointed framework.

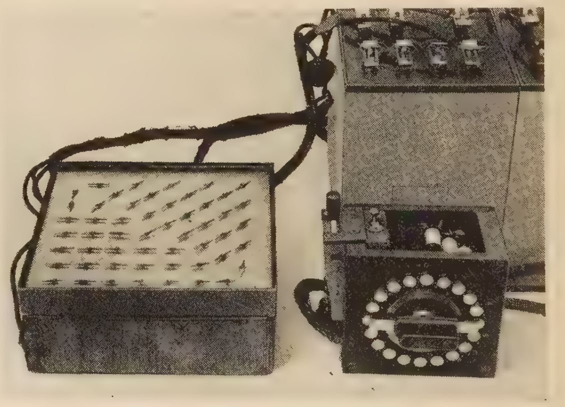

Fig. 2. Photograph of assembled apparatus.

The mutual magnetic effects of ideal bar magnets have been the subject of several investigations[3] since the time of Ewing. The mutual potential energy of each of two parallel magnets of moment μ, length l and separation r, is

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[3] See the excellent brief summary by R. Becker, *Theorie der Elektrizität* (Teubner, Leipzig, 1933), Vol. 2, p. 177.

$$W = -\mu^2 P_2/r^3 - (\mu^2 l^2 P_4)/r^5 + \cdots, \qquad (1)$$

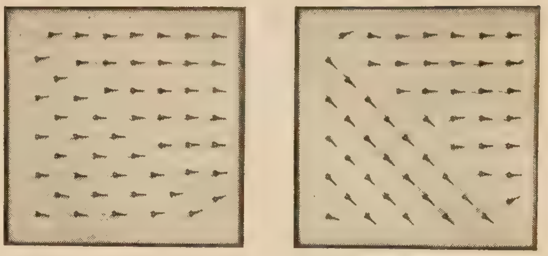
where P_2 and P_4 are trigonometric functions (Legendre) of the angle between either dipole axis and the line joining the centers of the magnets. Here the first term may be designated as the *dipole* term, the second as the *quadrupole* term, and so on. The energy of any assemblage may be calculated, in principle, by summing such terms for all pairs of magnets, and one of the summations which have been carried out is that for the cubic body-centered space-lattice of iron. The result of this calculation shows that the mutual magnetic energy depends upon the separation l of the poles of the magnets, and is zero when l is zero. That is, if a simple dipole is located at each lattice point the resulting magnetic field strength at any lattice point due to all of the other dipoles is zero, and it is only when a quadrupole term appears that one orientation with respect to the surrounding atoms becomes more or less stable than the others.

In general, the quadrupole term is different from zero when the magnetic dipoles associated with each lattice point are not located exactly at the lattice point. In the bar magnet considered in the foregoing example, the dipole distribution is extended along a line of finite length. In the case of electricity flowing in a circle having its center at the lattice point, the quadrupole term in the energy equation corresponding to Eq. (1) is of opposite sign and of somewhat different magnitude:[3]

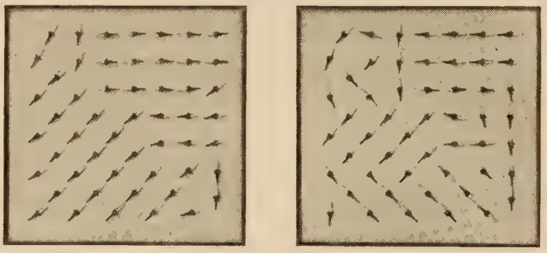
$$W_1 = -\mu^2 P_2/2r^3 + (3\mu^2 a^2 P_4)/r^5 + \cdots, \qquad (2)$$

where a is the radius of the circle on which the current exists. This circle can be thought of as covered with a uniform dipole density.

Returning now to the Ewing model and comparing it with a magnetic material as we visualize it today we may say that in the absence of an external field the mutual magnetic effects cause the pivoted magnets to line up in some one direction with respect to the axes of the plane lattice, and that in a magnetic material composed of cubic crystals the mutual magnetic forces between the atoms cause them to align themselves more easily in one direction than in another with respect to the crystal axes. In iron and in some iron-rich alloys this direction of "easiest magnetization" is parallel to a cubic axis, and of course in the absence of strain each of the six directions so defined is equally "easy;" in nickel and some nickel-rich alloys the direction of easiest magnetization is any one of the eight directions which are equally inclined to the three axes.[4]



(*a*) Saturation magnetization (*b*) Remanence



(*c*) Further reduction in magnetization (*d*) Demagnetized

FIG. 3. Model in various stages of magnetization, a, indicated. The magnetic field is in the horizontal directions or is zero.

In a real material, however, it is now rather well established that there are very powerful forces, not contemplated when Ewing made his model and proposed his theory, which maintain the dipole moments of neighboring atoms parallel. These are the electrostatic forces of "interaction" which Heisenberg suggested are powerful enough to align the elementary magnets against the disordering forces of thermal agitation, forces much larger than those of magnetic origin, for example the magnetic forces between atoms having any reasonable quadrupole moments.

The magnitudes of the interaction forces on the one hand and the magnetic forces on the other may be estimated and compared. The interaction energy will be of the order of magnitude of the thermal energy of agitation at the Curie point, the temperature at which the disordering forces of thermal agitation overcome the ordering forces of interaction. At the Curie point of iron (1040°K) this is of the order of kT or 10^{-13} erg/atom. The magnitude of the magnetic quadrupole energy is roughly equal to the magnitude of the magnetic potential energy $\int HdI$ necessary to magnetize a single crystal of the material in the direction of most difficult magnetization. For iron this is about 10^5 ergs/cm^3 or 10^{-18} erg/atom, less than the estimated energy of interaction by a factor of 10^5. Thus the electrostatic forces of interaction hold the spins parallel to one another and the magnetic forces merely favor particular directions in the crystal along which the spins tend to remain aligned in the absence of disturbing fields or stresses.

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[4] For an explanation of the different directions of easy magnetization in different crystals, see R. M. Bozorth and L. W. McKeehan, Phys. Rev. **51**, 216 (1937).

This alignment of atomic magnets by the forces of interaction does not extend over the whole of the magnetic specimen nor even over all of a single crystal in the body of the piece without change in the stable direction. For some reason not understood the alignment is limited to smaller regions of the order of magnitude of 10^{-7} to 10^{-9} cm^3, so that if they be cubes their edges are only about 10^{-3} cm long. These regions, generally called "domains," are discussed in the next section and the ways in which the magnetizations of the various domains change relative to each other and to the crystal axes may also be illustrated by the model.

Demonstration of the domain theory

Each pivoted magnet of the model is now to be considered as representing the magnetization vector in one domain ($>10^{15}$ atoms) of a ferromagnetic material. According to the model as constructed, the domains lie in two crystal grains, the grain boundary extending from the upper left-hand to the lower right-hand corner of each panel in Fig. 3. The model thus illustrates the idea due fundamentally to Weiss, that in the absence of an external field spontaneous magnetization exists, each domain being magnetized to saturation in some one direction in the material; and that this direction varies from one domain to another so that the net magnetization of all of the domains in a "demagnetized" specimen is zero. It shows also what Weiss did not know when he originally proposed his theory, that in a cubic crystal of iron the direction of magnetization in each domain is parallel to one of the six equivalent directions parallel to the cubic axes.

When a field is applied to a magnetic material the magnetization vectors first change from one direction of easiest magnetization to another which is more nearly parallel to the applied field. The model illustrates this. As the applied field is increased in strength until, and after, this process is complete (at the knee of the magnetization curve), the magnetization of the domains, and correspondingly the pivoted magnets in the model, begin to deviate from a direction of easiest magnetization and to approach the direction of the field until at saturation the magnetization and field are parallel.

The domain model gives just as good a representation of magnetic phenomena as Ewing's model does, since in fact it is the same apparatus. But the domain model has the advantage in that it corresponds more closely to our present conceptions. Perhaps this point is illustrated best by the Barkhausen effect. A study of this phenomenon shows that the sudden changes in magnetic moment which can be made audible correspond to the cooperative action of a great many atoms, far more than would be expected to change direction at once in Ewing's model.

In the domain model the directions of easy magnetization are determined by magnetic forces, as they are in actual materials, but in the model the forces are dipole and quadrupole forces acting between the magnets which represent domains, while in a magnetic material the magnetic forces are complicated resultants of similar forces between the separate atoms within each domain. The theory in its present state neglects entirely the magnetic effects between one domain and another.

Benj. H. Brown—

A Word Portrait of a Teacher of Physics

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Benj. H. Brown

IN 1924 Harvard University offered a scholarship of $1000 to the colleges and universities of the United States for the senior who should pass most creditably an examination in physics to be set by Harvard and marked by Harvard instructors. I do not know the total number of men who entered the competition but three seniors of Whitman College took the examination. The conditions for taking the examination were rigorously prescribed and the papers were immediately sent east to Harvard. In due course the names of the ten highest competitors were announced. The first name was that of a Whitman man, the second was also that of a Whitman man, and the third Whitman man was among the ten highest. The second grade was so close to the first that Harvard offered a special scholarship to the second Whitman man. All of these Whitman students were the pupils of Professor Benjamin H. Brown, who for over a quarter of a century had been the head of the physics department.

What manner of man was this teacher whose pupils won such nation-wide distinction in a single year and of whom the head of the physics department of the University of Washington said to me fifteen years ago: "Whenever I visit Walla Walla, which I do frequently, I always make a point of visiting the classroom and laboratory of Professor Brown because I regard him as the greatest teacher of physics I have ever known." The uniform judgment of his students was expressed twenty-five years ago by one of them in a private letter to me: "When I went to the Massachusetts Institute of Technology after graduating from Whitman, I found buildings and equipment far superior to anything I had seen at Whitman but I found nobody who as a teacher compared with Professor Brown."

Benjamin H. Brown was one of the most fortunate discoveries of my forty years as president of Whitman College. I was at the time the youngest college president in the United States, green and inexperienced, and I had gone to make a speech at Ripon College in Wisconsin with no thought of finding there new material for the faculty that I was trying to secure for the little institution which it was my duty to rescue if possible from extinction. Whitman had only six teachers, no endowment, and no assurance of long life. After I had made my speech I told President Merrell that I was looking for a few young men of ability and faith who would be willing to join in the adventure of trying to build Whitman College into a first-class institution. He told me that I ought to see Ben Brown, and made an appointment for me to meet him the next day when he could come in from the little country school where he was teaching.

The next morning, Saturday, I met a tall, broad-shouldered young man, erect and vigorous, modest and unassuming, with whom I at once began to discuss the vacancy next fall at Whitman College. He seemed to understand the pioneer character of the work and to take pleasure in the prospect. He accepted without hesitation the salary of $1000 which was all that I could offer him, and we parted with the understanding that he would be on hand for the opening of the College in September. We signed no contract, for he trusted me to carry out my agreement and I trusted him to devote himself whole-heartedly to the service of the College. For the next thirty years he gave all of his time and energy without reserve to building up the institution both as a loyal member of the faculty and as a teacher.

When he first came to Whitman in 1895, he occupied a settee rather than a chair, for the poverty of the college required that he should teach three natural sciences—biology, chemistry, and physics—in all of which he was at that time equally interested and at home. In 1899 he relinquished biology to a new member of the faculty, continuing with chemistry and physics between which he had no decided preference. When it became possible to establish a separate chair of chemistry in 1904, Brown chose almost reluctantly to keep on with physics and thenceforth gave his whole energies to the teaching of that science in which he gained increasing power and prestige during the next twenty-five years, although he never had the equipment which his genius deserved.

Benjamin Harrison Brown was born in Lamartine, Fond du Lac County, Wisconsin, March 4th, 1866, the son of Harrison H. Brown, a native of New York State, and of Louisa Maxfield, a native of Vermont. Brought up on a farm and accustomed to all kinds of farm work, he was twenty-one years old before he was able to get away from home when, in 1887 he entered the preparatory department of Ripon College. He worked his way through Ripon and graduated in 1894 with the degree of B.Sc. He was a faithful and unrelenting student who also found time to play baseball and hold with high honors the place of first baseman on the college team. Earnestness of purpose and an extraordinary capacity for hard work, both physical and mental, were his outstanding characteristics; whatever he did he did with his whole heart and brain. In 1897 he married Maud Merrell, the daughter of the president of Ripon College. With her he lived happily until her death in 1926. Their only child, Mrs. Amy Brown Thompson is now living in Spokane, Washington.

I asked twenty of Professor Brown's more distinguished students to tell me what they thought was the secret of his power as a teacher and I have woven together the substance of what they have written, avoiding repetition and eliminating what seemed to me unimportant. The contributors to the following symposium all hold the Ph.D. degree and are now engaged in the research laboratories of such institutions as Princeton, Massachusetts Institute of Technology, University of California, Union College, University of New Mexico, the National Bureau of Standards, the Mayo Clinic, the Memorial Hospital of New York City, the American Telephone and Telegraph Company, and Bell Telephone Laboratories; or in engineering work for states or great private industrial corporations. I have used their own words but have not indicated the author in order to avoid confusion. They agree in believing that Professor Brown was the most remarkable teacher under whom they ever studied but they account for his success as a teacher differently through laying emphasis on different aspects of his teaching. I hope that they will all be satisfied with my attempt to unify and summarize their statements.

* * *

"Professor Brown's name is on the lips of all of us Whitman physicists when we meet, and we have spent much time in trying to analyze his power as a teacher. But when it comes to a comprehensive explanation we find ourselves, as a rule, quite inarticulate. In my opinion his remarkable success as a teacher is due in large measure to five attributes.

"First: he is at heart a dramatic character. To him nature is literally full of wonders, as revealed by man's progressive unfolding of her secrets. He is able to instil in the students a similar feeling of drama, to thrill them as he himself is thrilled. It is his dramatic instinct which serves as a key to excite and hold the interest of the students. Whether they are scientifically inclined or not, I do not recall ever seeing a drowsy student in his audience.

"Second: he is able to show how our physical knowledge is obtained without going into details which to the beginner may be tiresome. The essential experiments and deductions or inductions which lead to the physicist's viewpoint in any particular instance are often presented by him through a few simple arguments sufficient for the beginner, without mentioning details which for a more rigorous logical development would be quite essential.

"Third: he has the faculty of stimulating individual thought. He can shock the student by a sweeping statement which may or may not be strictly correct, but which invokes new lines of thought both interesting and worthwhile. For instance, he would tell us that in our experience there are plenty of 'pushes' but there never was a 'pull'; after the first shock we would begin to think of electrical and gravitational forces, but his answer would be that we did not as yet understand these forces. Again, he would say that as much was known about electricity as about matter in any form, the object lesson here of course being that familiarity is not necessarily the same as knowledge.

"Fourth: I admired his handling of figures and equations, the speed and dexterity with which he reached his goal. While this may have been due to long practice he never seemed to work from memory, and I have never had another teacher who excited a similar respect. I believe his skill lay in his presentation rather than in his ability as a mathematician, and I think it was particularly effective in the elementary courses.

"Fifth: As to his personality, he has a thrilling voice, an unusually earnest, modest, and friendly manner, and a striking figure. I have never heard of a student who disliked him, and his advanced students loved him unanimously."

"As to my experiences with him, I can say that, after twenty-five years, during which time I have sat under noted teachers in great institutions, I feel that I have never encountered but one other man who is even in Professor Brown's class as an inspiring teacher, and this man is not a physicist. I find it difficult to put my finger on one thing and say this is the secret of his success, unless it is his own intense interest and appreciation, together with the gift, for it is a gift, of actually imparting his knowledge and kindling corresponding enthusiasm. I find myself now trying to copy his methods in my own lectures, and hoping that I may be half as successful in putting my ideas across.

"In the classroom he is an intensely interesting talker. His lectures are not formal at all, and his tone is not didactic, but conversational; you feel that he is talking with you, not at you. And as he talks he is continually filled with the wonder of what he is talking about and of what is still to be found out in this universe. Physics is never to him a complete subject, but a science which is constantly growing. I studied with him long before the advent of the quantum theory, the neutron, and artificial radioactivity, yet one of his favorite dreams or prophecies dealt with exactly those matters. He foresaw a time when we would take the atom apart and use the energy there available. Small wonder that some of us who are now actually dealing with these atomic disintegrations continue to feel the power of his vision.

"In the laboratory again we had the atmosphere of a living subject. Experiments were not cut and dried, with ready-made apparatus. They were developed with what we had, supplemented by sticks and strings and other makeshifts, and when they worked we knew why. When I knew Pupin, after I went to Columbia, he used to talk about the great teachers of his youth who could demonstrate physical principles with everyday things, and I used to think he might well have been talking about Professor Brown.

"He was endlessly patient and ready to give us time and encouragement; but he expected us also to work, and to work hard. The number of scheduled hours for a course became unimportant under his inspiration."

"I think probably that Professor Brown was a fine stabilizing influence because his character, ability, and training were an education when considered in the light of what a young person would consider worldly success. In any case he was more than a teacher to me. He was a study and an example. He had studied and taught nearly all the science existing in his time, and hence his outlook was wide. His vision was clear, and he had given such thought to nature and her laws that when he explained a phenomenon or developed a law it was with complete serenity. He was never intense nor unpleasant. He was simply an inherently honest thinker with a very great intellectual ability.

"I thank Professor Brown for giving me, all unconsciously perhaps on his part, the feeling that all nature shows evidence of orderly thought infinitely beyond our ability to understand, but that true growth can only be in the extension of our understanding along the ways of nature; that whether we perceive it or not there is only one right answer to any problem in life; that ultimately no one can make a thing right by authority; that to solve any problem of physical or human nature requires a keen searching out of all the forces involved and an answer which leaves all the forces at ease."

"He has an abiding interest in all natural phenomena, is a keen and inquiring observer, and has a great facility for stating problems in the language of the students and in terms of concepts familiar to them. He inspires tremendous confidence in his knowledge of the subject, and the greatest feeling of cooperation in all activities in the class and laboratory. We always knew what

Professor Brown wanted us to do, and I think that most of us tried our best to please him. I worked for him for five years, and I have often tried to think whether he ever told me what he wanted done. It seems that there must have been some other way of finding out what was important at the time."

"He never made the appeal to authority dogmatically. He always presented the evidence so far as it was known and available, and never hesitated to say 'I don't know' when the classroom discussion progressed beyond the frontiers of knowledge then known and organized. Yet contrasted with other less factual subjects so prevalent in a college curriculum, the students may have had the feeling that here at least was something reliable, something real, something that could be depended upon. Of course physics has grown far less materialistic than it appeared to be at that time but, even so, there is remarkably little that Professor Brown taught which needs to be discarded in the light of more recent discoveries.

"It is a relatively easy matter to develop a good physics department if the budget is ample; but to develop it with a woefully inadequate budget is an achievement worthy of the highest commendation. This is an accomplishment that requires great insight into the real essentials of physics, and it is one in which Professor Brown did not spare himself. For years he labored thirteen and fourteen hours a day to be sure that his students got a real opportunity to study the science."

"He somehow made cold scientific logic take on a warmth and beauty which lifted his students completely out of themselves. This was not done with elegant oratory but rather with the help of a few homely expressions said with the greatest modesty. When he saw good students working hard he quietly withdrew and let them probe for themselves. Sometimes he dispensed with his customary lectures when he saw his students were making progress without him."

"He had a wealth of illustrative examples which were simple, interesting, and exact for practically every principle he tried to explain. These examples were so varied that any student would see the science applied to the field of his chief interest. Regardless of how many times he repeated a lecture or an explanation, he always appeared to be interested in giving it.

"He exhibited a complete freedom from the driving ambition for personal advancement at the expense of the welfare of the student. His reward came indirectly through the honors received by his students."

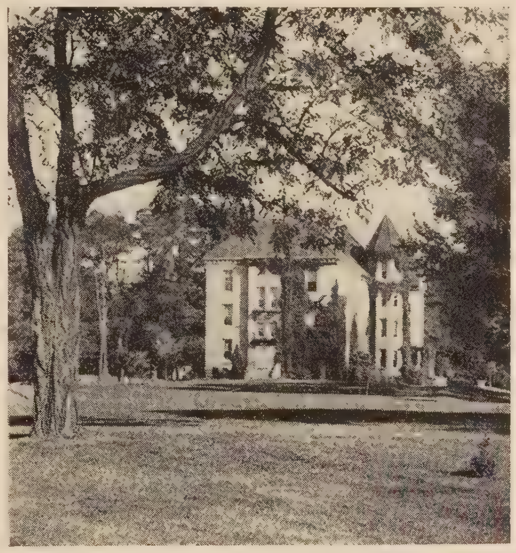
"His teaching was characterized by the judicious introduction of humor into the lectures without in the least jeopardizing the respect in which he was universally held. He did not try to cram us full of details which in a short time would become antiques on the shelves of memory, but did insist on our attaining a knowledge of vital and essential principles. He tried to encourage and develop powers of analysis."

"There was no bombast in his makeup, no desire for the limelight, no feeling that it was his job to reform everyone and to upset the prevailing economic system. His philosophy of life required him to live simply, to practice humility, and to love his fellow men. No half-way measures were acceptable to him. He required, for example, that his students must know the logic of a formula and be prepared to support their right to use it by having a comprehensive knowledge of the significance of the factors that enter into its construction. He set up an uncompromising requirement, which he administered patiently, that members of his classes should develop the confidence which arises from independent thinking and ability to reason through a proposition to a demonstrable conclusion."

"The thing that impressed me most about Professor Brown was his philosophy of life. From his position as a scientific observer of the physical world, he was impressed with the smallness of man and the exaggerated importance that man placed on his everyday affairs. He was a pure skeptic. I never knew him to be angry or in the least temperamental. He had almost infinite patience. He impressed me as a lonely man, one whose experiences with human beings had taught him not to trust them too far.

"He was an accomplished teacher of the first rank. He knew, I think almost unconsciously, how to inspire and interest students. None of his courses was easy, yet the popularity of his junior course in astronomy and geology attests to the fact that he could attract the general student.

"The subject matter of his physics courses would have been regarded as fundamental and outstanding in any college. Some of the reasons for his greatness lay in his use of the experimental method. His laboratory was largely the work of his own hands and brain. Although many of his experiments were standard ones, to each he added something of his own ingenuity. It would appear that instead of copying experiments he had thought each one out and made the essential ideas his own, and then reconstructed the experiment from his own knowledge. One of his outstanding experiments was the measurement of the mass of the earth. The apparatus for doing this was, I believe, the only one on the Pacific coast at the time. Here, as in all his experiments, he had the student approach the problem with the idea of determining the value for himself, and not of simply checking the accepted value. In another experiment, instead of measuring the candlepower of an ordinary lamp, he had us measure the candlepower of the moon. The standard experiment on the emissivity of a black body was turned into a problem to deduce the temperature of the sun from our measurements in the laboratory. He sent us to the chapel to determine its acoustical properties and to make our own recommendations as to how those properties could be improved. In our first physics course, we measured the speed of a rifle bullet; I can see him almost as if it were yesterday, doing those parts of this experiment that could hardly be trusted to our inexperience, pointing out all the factors, and then having us do them. Characteristic of Brown was the very next experiment; it was really a mental exercise, to deduce the average speed of air molecules from the air pressure and density, and then to find that the air molecule travels on the average just a little faster than did our rifle bullet. In another experiment we dropped shot on a piece of paper on which were drawn circles all of the same radius and tangent to one another. We counted the shot that fell in the circles and those that fell in the area between them. Since the ratio of the two areas depends only on π, the ratio of the numbers of shot in the two areas yields a value for this constant. We could not make enough trials of course to obtain a very accurate value, but Brown produced the record of all past experiments, averaged our value in and let us see how the value improved with increased number of trials. He also pointed out the fluctuations in the value up and down from the true value.



Billings Hall,
The science building at Whitman College.

"He put us through many exercises in thinking. One of these I particularly remember. From the surface tension one can deduce the work per molecule needed to pull apart the molecules in a cube of water 1 cm on a side. One also knows the energy necessary to convert such a cube into steam. The two energies must be the same and so one gets the number of molecules in 1 cm^3 of water. Brown would not stop there, of course, but would proceed to deduce the number of atoms of hydrogen in a gram of hydrogen and, finally, the charge of an electron in coulombs, all simple calculations from things easily measured in the laboratory.

"He used great ingenuity to design the experiments, when possible, so that it would not be easy to find the correct results without actually performing the experiments. He taught us to have faith in the values we obtained; to find the errors in our experiments and thus get better results. He tried to make us realize that in experimenting we were finding out something for ourselves; that the accepted values in the books might be wrong; that our experiments should indicate to us whether they were right or wrong. He tried to get us to decide for ourselves what the facts were without bias due to preconceived notions.

"It would be a mistake, and surprising, to say that this man did no research. He chose problems that were close to home. For example, he studied the factors involved in the pulling of loads by teams. Prosaic though it sounds, those who are familiar with this work recognize it to be an original contribution. Although isolated from the centers of research activity, Professor Brown maintained an active interest in the progress of physics and discussed with his advanced students important current papers. In my own case Professor Brown began teaching me physics while I was still in grammar school. On Saturday mornings he entertained, and taught, a group of boys with problems on mechanics, perpetual motion, hydraulics, engines, motors, etc. We enjoyed those Saturday mornings very much and I am certain that they were valuable to me in my subsequent study of physics."

"He made considerable use of simple apparatus, much of which he had devised and built himself. I remember an electric generator that consisted simply of a wooden axle and frame containing a coil of wire which rotated in the earth's magnetic field. We had the joy of operating a full-sized steam engine; of determining the temperature and chemical constitution of the sun. His lectures on radioactivity were prophetic of the importance of experiments only recently realized. As a basis for the atomic theory his approach was ideal. Can you wonder at his success as a teacher when we could envisage the triumph and mastery of man over his environment by the sheer power of simple experiments, the understandings of which were made the point of departure for our knowledge of the whole science. With him we were thus made powerful as well as ambitious."

* * *

Professor Brown's modesty is extraordinary. He has shrunk from all public recognition and has stubbornly refused various honors which were thrust upon him. He declined membership in the Whitman Chapter of Phi Beta Kappa to which he was elected and also membership in Sigma Xi to which the Chapter at a neighboring institution elected him in honor of his achievements. Since resigning from the physics department Professor Brown has spent his time in studying the geology of the surrounding region, riding on his bicycle from twenty to forty miles a day, in perfect health of body and of mind. His seventy-first birthday found him as always simple, sincere and serene, free from anxiety, and happy, I trust, in remembering the pupils whom he helped on their victorious way and who now rise up to call him blessed.

Acoustical, Mechanical and Electrical Analogies

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SINCE acoustical measurements generally are made with electrical instruments and in terms of electrical quantities, it is necessary to compare electrical quantities and units with acoustical and mechanical ones. Analogous relations exist between the electrical, mechanical and acoustical quantities and units, and a knowledge of them is helpful both in teaching and in experimental work in acoustics. Crandall[1] says,

> "The analogy between Eq. (3) [the complete equation of motion of a system of one degree of freedom] and the general equation of the electric circuit containing inductance, resistance and capacity [Eq. (3′)] will not be labored here. It will doubtless interest the student who has mastered alternating-current theory to note all such analogies as we proceed."

Stewart and Lindsay[2] say,

> "The comparison of acoustical wave problems with electrical oscillations is often very valuable, but it must be made with caution and only with reference to the differential equation involved."

Olson and Massa[3] say,

> "The use of elements in electrical circuit theory is well known. In the study of mechanical and acoustical systems, the analysis is facilitated by the introduction of elements analogous to the elements of an electrical circuit. That is, every mechanical or acoustical system may be looked upon as a combination of mechanical or acoustical elements. It is the purpose of this chapter to describe the action of mechanical and acoustical systems from this viewpoint."

Olson and Massa[4] also tabulate the corresponding

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[1] *Theory of Vibrating Systems and Sound*, p. 5.

[2] *Acoustics*, p. 54.

[3] *Applied Acoustics*, p. 17.

[4] Reference 3, p. 20.

TABLE I. *C.g.s. system.*

ELECTRICAL (e.m.u.)	MECHANICAL	ACOUSTICAL
Quantity	Quantity	Quantity
e.m.f., e	force, f	pressure, p
Charge, Q	displacement, x	volume displacement, X
Current, i	velocity, v	volume current, $\dot{X}$
Resistance, R	resistance, r_m	resistance, $r_a=\rho wk/2\pi$
Inductance, L	mass, m	inertance, $M_a=\rho l/A$
Capacitance, c	capacitance, $1/s$	capacitance, $c_a=V/\rho c^2$

TABLE II.

ELECTRICAL (e.m.u.)		MECHANICAL		ACOUSTICAL	
e	$M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}$	f	MLT^{-2}	p	$ML^{-1}T^{-2}$
Q	$M^{\frac{1}{2}}L^{\frac{1}{2}}$	x	L	X	L^3
i	$M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}$	v	LT^{-1}	$\dot{X}$	L^3T^{-1}
R	LT^{-1}	r_m	MT^{-1}	$r_a=\rho wk/2\pi$	$ML^{-4}T^{-1}$
L	L	m	M	$m_a=\rho l/A$	ML^{-4}
c	$L^{-1}T^2$	$c_m=1/S$	$M^{-1}T^2$	$c_a=V/\rho c^2$	$M^{-1}L^4T^2$

TABLE III.

RATIO	SOURCE e, f, p	DISPLACEMENT Q, x, X	VELOCITY $i, v, \dot{X}$	RESISTANCE R, r_m, r_a	INERTIA L, m, m_a	ELASTICITY $c, 1/s, V/\rho c^2$
E.s.u./e.m.u.	$L^{-1}T=1/\theta_1$	$LT^{-1}=\theta_1$	$LT^{-1}=\theta_1$	$L^{-2}T^2=1/\theta_1^2$	$L^{-2}T^2=1/\theta_1^2$	$L^2T^{-2}=\theta_1^2$
Mech./e.m.u.	$M^{1/2}L^{-1/2}=1/\theta_2$	$M^{-1/2}L^{1/2}=\theta_2$	$M^{-1/2}L^{1/2}=\theta_2$	$ML^{-1}=1/\theta_2^2$	$ML^{-1}=1/\theta_2^2$	$M^{-1}L=\theta_2^2$
Acoust./e.m.u.	$M^{1/2}L^{-5/2}=1/\theta_3$	$M^{-1/2}L^{5/2}=\theta_3$	$M^{-1/2}L^{5/2}=\theta_3$	$ML^{-5}=1/\theta_3^2$	$ML^{-5}=1/\theta_3^2$	$M^{-1}L^5=\theta_3^2$
Acoust./Mech.	$L^{-2}=1/\theta_4$	$L^2=\theta_4$	$L^2=\theta_4$	$L^{-4}=1/\theta_4^2$	$L^{-4}=1/\theta_4^2$	$L^4=\theta_4^2$

names and symbols commonly used for the analogous quantities in the three systems. For example, electric current i, velocity u, and volume current U are tabulated as analogous quantities. The following outline, arranged by the present authors, shows how well these analogies hold and provides a help for future reference.

I. One obtains the analogies between the electrical, mechanical and acoustical quantities by comparison of the coefficients occurring in the differential equations for the forced oscillations of an electric charge in a circuit, the forced oscillations of a particle and the forced vibrations of the medium produced in an acoustical system. The equations of motion of: (1) an electric charge Q in a circuit containing a resistance R, capacitance C and inductance L, and subject to an impressed electromotive force E cos wt; (2) a particle of mass m and one degree of freedom acted upon by a periodic force F cos wt, a restoring force $-sx$, and a frictional retarding force $-r_m\dot{x}$; (3) a medium in an acoustical system of one degree of freedom[5] (Helmholtz resonator, for example), where p is the applied pressure, X is the volume displacement, A is the area of the opening, V is the volume of the cavity, ρ is the density of the medium, and $k=w/c$ are, respectively,

$$L\ddot{Q}+R\dot{Q}+Q/c=E\cos wt=e, \tag{1}$$

$$m\ddot{x}+r_m\dot{x}+x/(1/s)=F\cos wt=f, \tag{2}$$

$$(\rho l/A)\ddot{X}+(\rho wk/2\pi)\dot{X}+X/(V/\rho c^2)=P\cos wt=p. \tag{3}$$

A good comparison between the coefficients of the corresponding derivatives appearing in these three equations is obtained by means of Table I, which is similar to that given by Olson and Massa.[4]

II. With M, L, T, used to denote the fundamental units, the dimensions of the foregoing quantities are those given in Table II. In the case of the electrical units the dielectric constant and the permeability are considered to be dimensionless.

III. The ratios of the dimensions of analogous units in the three systems were worked out and tabulated in Table III. The electrostatic and electromagnetic systems are included in the table. It should be observed how the ratio of the dimensions of charge in the two electrical systems appears in all of the other ratios of the two systems. For example, the ratio of electrostatic to electromagnetic charge is $L/T=\theta_1$; and all of the other ratios of these two systems are seen to be functions of θ_1 as shown by comparing the ratios in the top horizontal row. Likewise, any other ratio between dimensions of similar units of any two systems is a function of the ratio of displacements in the same two systems. Furthermore, these ratios have analogous forms in the three systems as shown by comparing the ratios in the vertical columns of Table III.

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[5] Reference 2, p. 49; reference 3, p. 25.

Some Elementary Laboratory Experiments in Heat and Optics

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Heat

LABORATORY courses in heat as usually given have often impressed us as being rather unsatisfactory, because, whereas the really important things are the first and second laws of thermodynamics, it is with the first law and the properties of materials that these courses ordinarily are concerned. It is not difficult to find experiments having to do with the second law and we believe that the write-ups for them should bring this law into the foreground.

Consider, for example, the common experiment in which the student measures the vapor pressure of water as a function of temperature. In our laboratory the method of the experiment is explained and the student is instructed to use his data to make a plot of p as a function of T. What follows is quoted from our instructions:

> The curve you get should look rather like Fig. 189 of the text. This curve is not of any recognizable form and so is not good for extrapolation nor as good as it might be for interpolation. Moreover, not understanding the reasons for the shape of the curve, we cannot guess whether the curve for some other liquid will look the same. As a matter of fact, when plotted in this way, the curves for different liquids look very different, and it would seem that each liquid must be the subject of a separate investigation.
>
> But we will now show, with the help of the second law, that all such vapor pressure curves are essentially the same, that when plotted on proper axes they turn into the simplest of all curves—a straight line—and that the data we have taken may be used to find the heat of vaporization of water!

There follow instructions for deriving Clapeyron's equation and the approximate vapor pressure equation,

$$\log p - \log p_0 = \frac{L}{R}\left(\frac{1}{T_0} - \frac{1}{T}\right).$$

The student is then directed to plot $\log p$ *vs.* $1/T$ and to determine the heat of vaporization L from the slope of the resulting approximately straight line. Then,

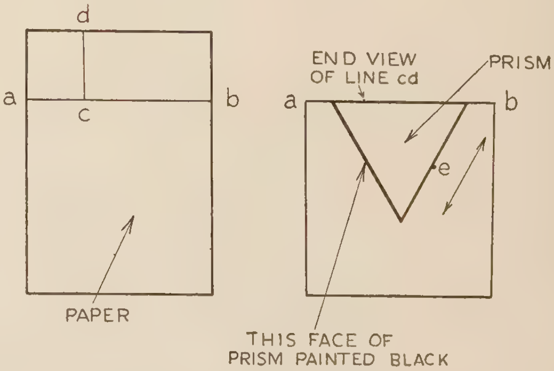
> It is to be emphasized that the extra information and understanding of the problem which we have attained result from the use of the second law; no amount of finessing with the law of conservation of energy (first law) will advance the problem at all.

Instructions are given for working various problems. Then finally,

> Just what this experiment is regarded as accomplishing depends considerably on the point of view. Taking the exact expression $dp/dT = L/T\Delta v$ and considering dp/dT as measured here, and L and Δv as known from independent experiments, one can solve for T, so that the present experiments furnish a means of establishing a Kelvin temperature scale; that is, one with T such that the change of entropy in a reversible cycle really is zero. Or, one can consider that the Kelvin scale is better established by manipulations with gas thermometers and porous plug experiments, in which case the present experiment provides a check on the assertion that the second law works irrespective of whether water or a perfect gas is used for a working substance.

Optics

Among the first optics experiments is a simple demonstration of total reflection. The student is provided with a piece of paper ruled with two fine lines as in Fig. 1*a*. He very carefully creases the paper along the line *ab* and places on it a triangular piece of plate glass as in Fig. 1*b*. By placing the eye in the general region of the double arrow it will be found that to the right of a certain plane, light comes from the paper through the prism while to the left it does not. The eye is moved until this boundary coincides with the line *cd* and a pin is inserted in the line of sight



Figs. 1*a* (left) and 1*b* (right). Total reflection.

as at e. The index of refraction is then easily found. Besides being a neat demonstration of total reflection, this experiment gives astonishingly good determinations of the index of refraction, and for two reasons: (1) only one angle is measured, the angle of incidence being automatically fixed at 90°; (2) the rays emerge almost normal to the prism face so that if the pin is not quite in contact with the prism the error introduced is small. On the other hand, great care must be taken to keep the paper at the line ab in close contact with the edge of the prism and we supply the student with a clamp for this purpose.

To demonstrate the wave theory of light and also to give the student a new point of view on ordinary lenses we use zone plates. The theory of image formation with such plates is fairly obvious but we have not found it in common books on physical optics and so a sketch of it may be useful. We quote from the manual:

> For purposes of comparison it is useful to understand the working of an ordinary lens from the point of view of the wave theory. From this point of view, a converging lens is made thicker at the center so that, because waves travel more slowly in glass, all waves starting at a given point on one side will arrive simultaneously at the focus on the other; that is, waves going to the edge travel a greater total distance than those through the center but less of this distance is in glass where the speed is lower. This idea can be developed quantitatively.

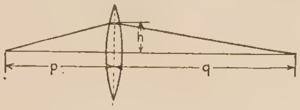


FIG. 2. Wave theory of a thin lens.

> We will suppose the lens to be thin and that, in Fig. 2, $(h/p)^2 \ll 1$ and $(h/q)^2 \ll 1$. Now rays at height h traverse less glass than those at height zero by an amount proportional to h^2, say $ah^2/2$, so that the optical path is less by $(\mu-1)ah^2/2$. Now we write down an expression asserting that for all heights h the optical-path length is the same:
>
> $$(p^2+h^2)^{\frac{1}{2}}-ah^2(\mu-1)/2+(q^2+h^2)^{\frac{1}{2}}=p+q.$$
>
> We have neglected the lens thickness. Now h is small compared with p and q so we can expand by the binomial formula. Doing this and canceling, etc., we find $h^2/p+h^2/q=ah^2(\mu-1)$. It is observed that h occurs to the same power throughout and can therefore be canceled. This means that a single pair of values, p, q, will make the path independent of h for all values of h; that is, the lens really forms an image. The quantity a is of course related to the curvatures of the lens.
>
> A zone plate is a sheet of plane glass with opaque rings on it and looks much like a target. A section might look like Fig. 3 and the ring sizes h_1, h_2, h_n are so adjusted that the various allowed paths are *not* the same but differ by an integral number of wave-lengths, so that all the waves arriving at the image point are in phase and add to produce the image. Compare Sec. 413 on diffraction gratings.

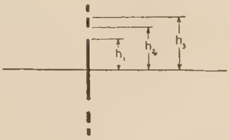


FIG. 3. Section of a zone plate.

> We next find out the proper values of h_n. Plainly the difference in path between a wave going from p to q at height h_n and one going at height h_{n+1} must be just $\lambda/2$. Proceeding as before, we have
>
> $$(p^2+h_n^2)^{\frac{1}{2}}+(q^2+h_n^2)^{\frac{1}{2}}-p-q=n\lambda/2.$$
>
> Expanding, we obtain
>
> $$h_n^2(1/q+1/p)=n\lambda, \quad \text{or} \quad 1/p+1/q=\lambda n/h_n^2.$$
>
> This means that we should make n/h_n^2 a constant, call it $1/h_1^2$, in which case the zone plate will act like a lens of focal length $f=h_1^2/\lambda$.

The student verifies the "lens formula," measures the focal length and h, and compares theory and experiment, taking λ as given. Or, the experiment might be regarded as determining λ. Sodium burners or neon lights are used for sources.

Although most people are quick to appreciate the value of such an experiment it seems that it is seldom employed in elementary laboratories. Perhaps the reason for this is the fear that it would be difficult to obtain satisfactory zone plates. If certain points are observed, however, there need be no trouble. First, one must decide on how many rings to have in the zone plate. By increasing the number of rings, both the intensity and the theoretical resolving power are increased. But the rings soon become inconveniently close, and, as for the intensity, the eye is so sensitive that a small number of rings is ample. A high resolving power is hardly needed and, moreover, it is a question whether, in practice, increasing the number of rings increases the resolving power because of slight inaccuracies in placing the rings. We therefore use only about 25 rings. The next question is how to make the zone plates. This is best done by making a drawing of convenient size and having a small copy made by a photoengraver, using wet collodion plates. With monochromatic light such a zone plate gives an image quite comparable with that given by a lens.

We have also capitalized on the photoengraver's ability to make beautifully sharp black and white copies in an experiment on diffraction gratings. Three parameters are needed to describe a plane grating; these may be taken to be the grating space, the ratio of opaque to transparent spaces, and the number of lines. (We disregard the length of the lines.) It is desirable to have the student try the effect of varying each of these parameters separately. To make this possible we simply drew the needed gratings on bristol board and had a photoengraver copy them on a reduced scale. We use 1, 2, 3, 4, and 15-line gratings, all with the same grating space and line width, a 15-line grating with the same spacing but different line width, and a 15-line grating with finer spacing but a similar opaque-transparent ratio. All six gratings are on one piece of glass. The weak intermediate maxima are easily found when using 2, 3, or 4-line gratings and, in fact, all the standard grating theory is easily verified.

Laboratory problems

For the engineers' manual we have found a number of problems that can be solved easily with elementary calculus, but not easily without calculus, and that are intimately connected with the experiments in question. In some cases their solution is actually necessary for a complete understanding of the experiment, and we feel that their inclusion in the manual helps to convince the student of the value of mathematics in physics. Unfortunately, problems useful enough to be interesting to the student are apt to be rather difficult. In cases of this kind we add hints which amount to an outline of a possible solution and also state some of the intermediate conclusions so that the student can, in the course of the solution, find out whether he is on the right track.

The following problems will serve as examples.

1. *Thermal expansion.*—Consider the general case in which the coefficient is a function of temperature, and suppose that it has been measured for various temperatures. Then the equation $\alpha=(1/L)(dL/dt)$, which was used in the experiment, may be considered as a differential equation whose solution will give the relation between length and temperature. Show by substitution in the differential equation that its solution is

$$L=L_0 \exp\left(\int_{t_0}^{t}\alpha dt\right), \tag{3}$$

where L_0 is the length at some given temperature t_0 and the function "*exp* of some variable x" is simply a shorthand notation for e to the power x. It is not actually necessary to use Eq. (3) in any practical cases because the coefficient is always very small, even when it is variable. Therefore the exponential function may be expanded in a power series and only the first two terms retained. Do this. The result is the relation which must actually be used unless the coefficient is a constant.

2. *Electric Motors.* In an experiment with a motor the student keeps the armature voltage constant and reduces the field voltage whereupon the motor speeds up. There follows:

Your results may be explained qualitatively by saying that when the field is reduced, the back e.m.f. drops and the armature current increases more than enough to make up for the loss in field strength; hence the force on the armature wires is increased and the motor accelerates. The current increases so rapidly because it is governed by the equation $I=(V-E)/R_A$; a small change in E makes a large change in $V-E$. Obviously, however, there is a limit to how much the field can be decreased as a motor with no field at all does not sound very practical. To investigate the question mathematically, proceed as follows: If F is the force on the armature wires, ϕ the flux from one field pole, s the speed of the armature, I the armature current, R_A the armature resistance, and V the line voltage, then $F=aI\phi$, and $V-bs\phi=IR_A$, where a and b are constants that take into account the dimensions of the motor, number of wires, etc. You can solve these equations for s in terms of a, b, V, R_A, F and ϕ. Now assume that the force F required to keep the machine moving is constant. This is only qualitatively true but will be a good enough assumption for the present purposes. You now have s expressed in terms of constant quantities and ϕ. Now differentiate and find $ds/d\phi$. If this is negative, it means that s increases when the field strength decreases. Show that when $V>2IR_A$ the speed increases as the field decreases, but that when this point is passed the speed decreases. Estimate the maximum speed your motor would attain if the field were decreased to this point and the motor did not explode.

3. *Microscopes.* As usually constructed, high power microscopes are focused by moving the whole microscope to and from the object. It is found that the adjustment provided for this purpose must be exceedingly fine. Suppose you are a designer and want to find out just how fine it must be. Proceed along the following lines. The image will be seen fairly well by the eye if it is anywhere between 25 cm and ∞ from the eye and this looks as if focusing ought to be easy. Find by straightforward calculation how much p for the eyepiece can be changed without causing the image to go outside this range; assume the eyepiece to have a focal length of 2.5 cm. This tells you how much q for the objective can vary and the

next problem is to find out the change in p for the objective to which this corresponds. There follows a calculus method for doing this. If you do not want to use this method you may use a slide rule; but seven-place logarithms are not allowed.

We want to find the small change in p, call it Δp, that corresponds to a small change of Δq. We may approximate the ratio between the two by the derivative dp/dq. To find this, get an expression for p in terms of f and q and differentiate. By utilizing the original equation you can throw your result into the neater form $dp/dq = -(p/q)^2$. For a numerical example let $q/p = 100$, so that the total magnification is 1000. Find the change in p that will move the image seen by the observer from ∞ to 25 cm.

A Brief Graphical Treatment of Fraunhofer Diffraction for Parallel Slits

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FOLLOWING M. Cornu's[1] graphical method of discussing the Fresnel type of diffraction, M. G. Sagnac[2] applied the graphical or geometric method to Fraunhofer diffraction for parallel-slit apertures. The diffraction equations were obtained by Sagnac for single as well as multiple slits without the usual integration processes. At the present time many optics texts mention the graphical method as a means of obtaining the diffraction equations for parallel-slit apertures but few take up its application in any degree of completeness.

This paper presents a graphical treatment of the Fraunhofer type of diffraction for multiple-slit apertures which is somewhat briefer than others and which employs some different arguments. The discussion of the single slit follows closely that given by Sagnac.

Fraunhofer Diffraction for a Single Slit

At the position O in the focal plane of the lens of Fig. 1 the vector amplitudes of the elementary wavelets from the aperture a are in the same phase (same direction), as indicated by Fig. 2.

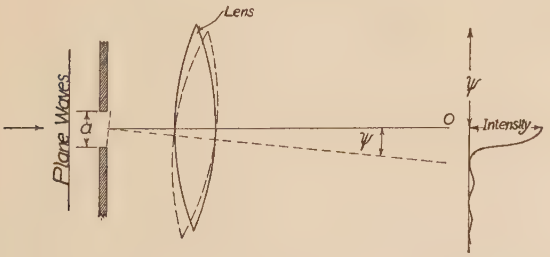

Fig. 1. Diagram of an arrangement for observing the Fraunhofer type of diffraction with a single slit, with a free-hand sketch of the intensity of the diffracted light as a function of the angle from the zero-order position.

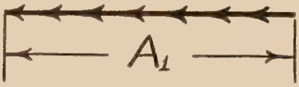

Fig. 2. Vector representation of the amplitude of the diffracted light from a single slit at the zero-order position.

At some angular position ψ from O in the focal plane of Fig. 1, the amplitude vectors will not be in the same phase, and the resultant amplitude will be C_1 as shown in Fig. 3. (Since the amplitude vectors in succession describe a uniform phase change they will, neglecting any effect of obliqueness, form the arc of a circle of length A_1.) By reference to Fig. 3 it is possible to write

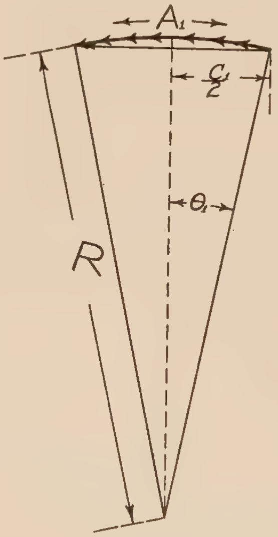

Fig. 3. Vector addition of the amplitudes of the elementary wavelets from a single slit at some position removed from the zero order.

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[1] J. de phys. **3**, 5 (1874).
[2] J. de phys. **7**, 28 (1898).

$\theta_1 = A_1/2R$ and $\sin\theta_1 = C_1/2R$. Thus

$$C_1 = A_1(\sin\theta_1)/\theta_1, \tag{1}$$

or

$$I_1 = I_0(\sin\theta_1/\theta_1)^2, \tag{2}$$

where I_1 represents the intensity at the angular position ψ, I_0 the intensity at the position O, and θ_1 the phase difference of the combining wavelets from the center and an edge of the slit. The phase difference θ_1 is equal to $\pi(a/\lambda)\sin\psi$ for the wave-length λ.

FRAUNHOFER DIFFRACTION FOR N EVENLY SPACED SLITS

If, in Fig. 4, light were considered to travel through one slit of width b equal to the combined width of an aperture and an opaque space, the arc B_1 of Fig. 5 would represent in length the magnitude of the resultant vector amplitude at the zero-order position O. At some angular position ψ from the zero-order position the phase difference for elementary wavelets from corresponding parts of successive slits is represented in Fig. 5 by $2\varphi_1$.

Since the opaque spaces (shaded in Fig. 4) between the slits do not transmit the elementary wavelets, the arc B_1 shows the difference of phase for combining wavelets from corresponding parts of adjacent slits; and the resultant of B_1 must be equal to C_1, which is the resultant of A_1 for a single slit. Thus, according to Fig. 5 (neglecting effect of obliqueness), the resultant vector amplitude of the elementary wavelets from N evenly spaced slits may be obtained through the relations $\varphi = N(B_1)/2r$ and $\sin\varphi = C/2r$, or

$$C = N(B_1)(\sin\varphi)/\varphi. \tag{3}$$

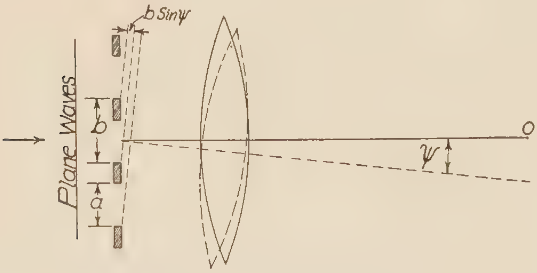

FIG. 4. Diagram of an arrangement for the case of a number of parallel slits.

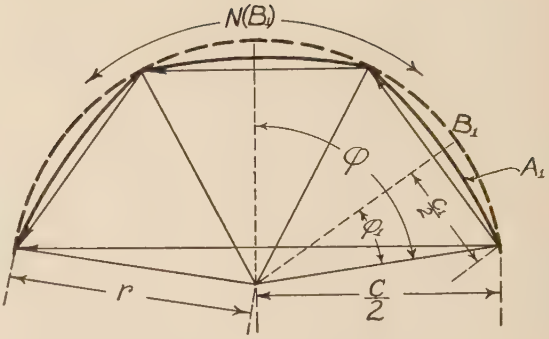

FIG. 5. Vector polygon for the resultant amplitude of the elementary wavelets from a number of parallel slits at some position removed from the zero order.

However, $\varphi_1 = B_1/2r$ and $\sin\varphi_1 = C_1/2r$. Thus $B_1 = C_1(\varphi_1)/\sin\varphi_1$ and Eq. (3) may be written in the form $C = NC_1(\varphi_1/\sin\varphi_1)(\sin\varphi/\varphi)$; or, since $N\varphi_1 = \varphi$, in the form

$$C = C_1(\sin N\varphi_1/\sin\varphi_1). \tag{4}$$

By using the value of C_1 from Eq. (1) the result is

$$C = A_1(\sin\theta_1/\theta_1)(\sin N\varphi_1/\sin\varphi_1), \tag{5}$$

or

$$I = I_0(\sin\theta_1/\theta_1)^2(\sin N\varphi_1/\sin\varphi_1)^2, \tag{6}$$

where I is the intensity at the angular position ψ for N slits, and I_0 is the intensity at the zero-order position for a single slit.

By reference to Figs. 4 and 5 it is seen that the intensity of the diffracted light of wave-length λ may be expressed in terms of a, b and ψ by the relation

$$I = I_0 \frac{\sin^2[\pi(a/\lambda)\sin\psi]}{[\pi(a/\lambda)\sin\psi]^2} \frac{\sin^2[N\pi(b/\lambda)\sin\psi]}{\sin^2[\pi(b/\lambda)\sin\psi]}. \tag{7}$$

For all the foregoing relations ψ should be restricted to small angles in order that Huygens' principle may serve as a suitable approximation, and the limiting value of Nb should be such that coherence may be assumed for the wavelets from the several slits, with the various values of ψ.

APPARATUS AND DEMONSTRATIONS

A Determination of Planck's Constant with a Calorimeter

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In many laboratory experiments on the determination of the fundamental constants of atomic physics, complicated auxiliary apparatus diverts the attention of the student from the main purpose of the experiment. It is most desirable, therefore, to offer experiments in which the simplest and most familiar technic serves for the determination of the fundamental constants. In the present experiment Planck's constant is measured with a calorimeter. As in any other determinaton of this constant, the knowledge of the constants of the electron is presupposed. The student has an opportunity to measure these constants in any laboratory course in modern physics.

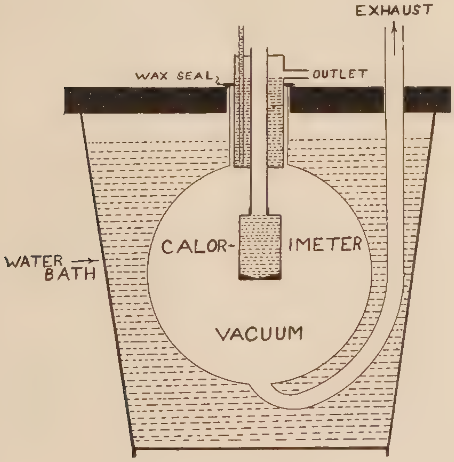

Fig. 1. Diagram of apparatus.

The only energy received by the blackened calorimeter surface of known temperature T_2 is the radiation from another black body of known temperature T_1. The area of the calorimeter surface and the flow of energy into it are measured, and then E, the energy received per unit area and time, is calculated. The Stefan-Boltzmann law $E=\sigma(T_1^4-T_2^4)$ permits the calculation of the constant σ, and then h can easily be derived.[1]

This method for the determination of Planck's constant was applied by Shakespear[2] in 1911. He observed the transfer of energy between two black plates of temperatures 100° and 15°C. Since he performed the experiment at atmospheric pressure his greatest difficulty was to take into account the transfer of heat by the air which exceeded even the transfer by radiation. A precise determination of h by the same method but at low pressure (1 mm) was made by W. Westphal.[3] He carefully checked all sources of error. Again, a major difficulty was to determine the transfer of heat through the residual gas.

Modern pumps will produce a vacuum so high that transfer of heat through the gas is eliminated. Westphal found that the degree of blackness of metal surfaces, blackened by the usual methods, was as much as 95 percent; thus it will be sufficient in the students' laboratory to assume that the surface is an ideal black body. The remaining problem is to support the calorimeter in vacuum in such a manner that no conduction of heat takes place through the support.

Apparatus.—Fig. 1 shows the apparatus. The source of black body radiation is the inner surface of a 3-*l* glass bulb. The bulb is covered on the inside with lamp black, and is connected through a side tube and a CO_2 trap to a mercury diffusion pump and a fore pump. If one omits the CO_2 trap, mercury vapor will be admitted to the hollow enclosure and cause a transfer of energy by conduction amounting only to 1 percent of the transfer due to radiation. The bulb is immersed in boiling water.

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[1] F. K. Richtmyer, *Introduction to Modern Physics*, ed. 2 (McGraw-Hill), pp. 256, 213.

[2] Proc. Roy. Soc. **A86**, 180 (1911).

[3] Ber. d. D. physik. Ges. **10**, 987 (1912).

The blackened calorimeter cup, 5.1 cm high and 3.2 cm in diameter, is drilled out of solid brass. A ring stirrer with a thin handle (not shown in Fig. 1) is built in before the bottom plate is soldered on. After the cup has been weighed it is screwed to a thin-walled brass tube which serves as a support and admits the thermocouple. The screw connection is made tight with beeswax-rosin cement. The brass tube need be only wide enough to accommodate the handle of the stirrer and the thermocouple. The upper part of this brass tube is soldered into a water jacket which is kept at constant temperature with running water. The top of this jacket has a hole for inserting a thermometer (not shown in Fig. 1). The water jacket is cemented with sealing wax to the top of the 3-*l* glass bulb. The bulb, in turn, is sealed to the top plate of the water bucket. (A rubber plate connection between the glass bulb and the top plate may be worth trying as a substitute for sealing wax.) The bottom of the calorimeter has a conical shape inside so that the water can be completely drained out. The surface area, water capacity, and water equivalent of the calorimeter are measured before the apparatus is assembled.

It is important that the calorimeter receive energy exclusively from black body radiation. If the temperature T_1 of the bulb is 100°C, the radiation from it will be black; for even if the inside surface of the glass bulb is not perfectly black, the shape of the emitter as a hollow enclosure will make the radiation black. The effect is not spoiled to any considerable extent by the presence of the cool calorimeter in the enclosure, since its area is comparatively small. It is much more difficult, however, to make the surface of the calorimeter cup black. In order to approximate the effect of a hollow enclosure a deep thread was cut on the lathe into the surface of the cup and grooves were cut into the top and bottom plates. The surface was then sandblasted and blackened with "Kodalak" [4] and lampblack. According to Westphal, who did not apply sandblasting, we are sure of a surface absorptivity larger than 95 percent for black body radiation at the existing temperatures. The surfaces of the supporting tube and water jacket are nickel plated so that they do not emit and absorb radiation appreciably.

The temperature T_2 of the calorimeter must be determined with considerable accuracy, and yet without time lag since its change with time is to be measured. Hence, instead of a mercury thermometer, one should use a thermocouple, for example, copper-constantan, connected to a galvanometer that has a period of only a few seconds. The deflection ought to be several centimeters per degree.

Procedure.—While the water bath is heated to the boiling point the calorimeter is kept cool by changing the water in it every few minutes. The temperature of the water jacket, which is kept constant by running tap water, is measured. A Dewar flask containing water of the same temperature as the jacket, holds the other junction of the thermocouple. This is preferable to placing the junction in the water jacket itself, for small fluctuations of its temperature would affect the result with their full value. On the other hand, if the junction is in the Dewar flask, fluctuations in the water bath cause only a minor transfer of heat through the supporting tube. When the water in the bath is boiling, the calorimeter cup is cooled several times with ice water, finally allowed to heat, and its temperature T_2 is measured as a function of time. In order to eliminate conduction of heat through the supporting tube, the measurements are made over a temperature range that includes the constant temperature of the water jacket, perhaps beginning two degrees lower and ending two degrees higher. The temperature-time curve is plotted and from it one can easily read the gradient. From this and the known constants of the calorimeter, the quantity E and constant σ can be calculated. The results have an accuracy of about 7 percent. Since Planck's constant is inversely proportional to the third root of the Stefan-Boltzmann constant, it is obtained with a correspondingly higher accuracy of 2 or 3 percent.

If one tries the experiment with a mercury thermometer instead of the thermocouple, a rather small instrument is advisable. The Beckmann thermometer, for which the apparatus described was originally built, has too large a thermal capacity for accurate determinations when the temperature is changing rapidly.

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[4] Eastman Kodak Company.

An Interesting Demonstration of the Combination of Two Linear Harmonic Vibrations to Produce a Single Elliptical Vibration

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IT is well known that two linear harmonic vibrations differing in phase by an appreciable amount combine to produce elliptical harmonic motion, or circular motion in the special case where the amplitudes are equal and the phase difference $\pi/2$. This is not to be confused with the production of Lissajous' figures by two linear harmonic vibrations of different frequencies and constantly varying phase differences. The effect demonstrated is often used in the explanation of the production of elliptically polarized light in a uniaxial crystal by a beam of plane polarized light incident normal to the optic axis, the electric vector making an arbitrary angle with the principal section of the crystal. The difference in the velocities of the ordinary and extraordinary rays introduces a phase difference which results in the elliptic vibrations of the resulting beam.

The demonstration piece to be described can be constructed in fifteen minutes with the aid of an ordinary pocket knife. It consists of a notched hardwood stick of rectangular cross section attached to the end of which is a small pitchless propeller. This pseudo-propeller is mounted loosely on a pin in the end of the stick (Fig. 1*a*). Upon stroking the stick with a pencil the propeller will be set spinning, the direction depending on the inclination of the pencil to the smaller cross-sectional dimension of the stick. The two possibilities, with the resultant directions of rotation, are illustrated in Fig. 2. The pencil is held normal to the length of the notched stick along which it is rubbed. The notches merely provide a means of producing forced vibrations in the stick.

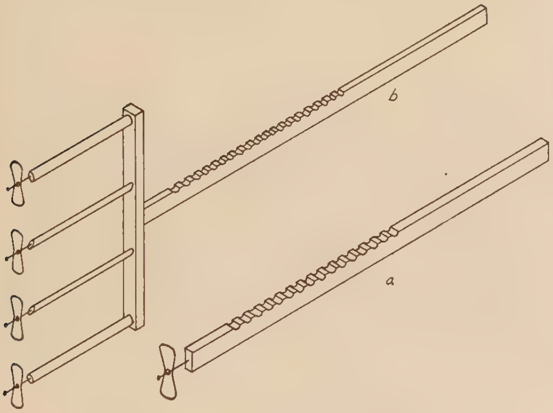

FIG. 1. Two forms of the device.

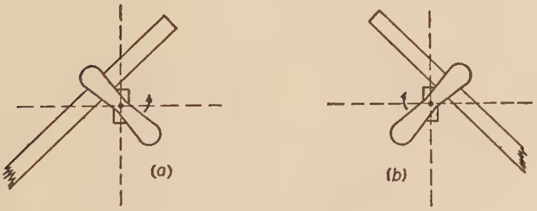

FIG. 2.

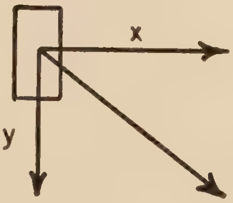

FIG. 3.

It is evident that the vibration produced by the pencil will have components parallel to the two cross-sectional dimensions of the stick which we shall label x and y as in Fig. 3. The relationship between the amplitudes as shown is only approximate, due to differences in the resonant frequencies for vibrations along the two axes. Since we are dealing with small vibrations we may assume harmonic restoring forces and the equations of motion will take the following form for forced vibrations of frequency ν:

$$d^2x/dt^2+2R\,dx/dt+kx=A\cos 2\pi\nu t,$$

where $2R$ is the damping factor per unit mass, k the coefficient of restitution per unit mass, and A the amplitude of the driving frequency divided by the mass. Mass as used here refers to the equivalent mass in the line of the vibration as traced by the end of the stick. The solution of this equation involves two terms, a transient term and a term containing the forced vibration,

$$x=Ce^{-Rt}\cos(2\pi\nu_1 t+\alpha_1)+\frac{A\cos(2\pi\nu t-\beta_1)}{[(k-4\pi^2\nu^2)^2+16R^2\pi^2\nu^2]^{\frac{1}{2}}}.$$

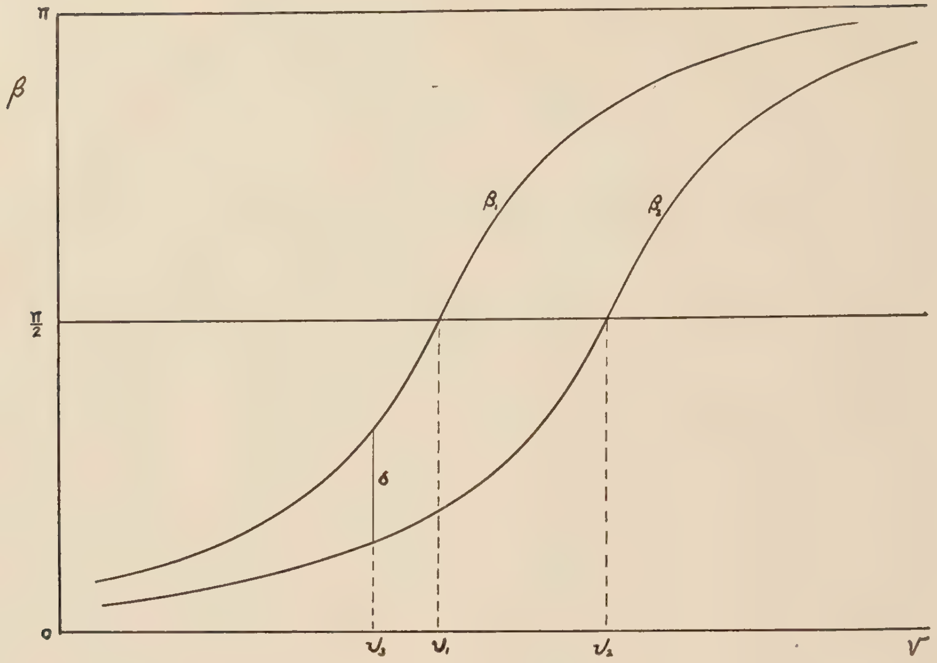

FIG. 4. Plot of phase factors *vs.* frequency.

Since the damping is appreciable in the case with which we have to deal, the first term is of no interest. Our particular interest is in the phase factor β_1 in the second term, which is given by the relation

$$\beta_1 = \tan^{-1}\frac{4\pi\nu R}{k-4\pi^2\nu^2}.$$

The phase factor β_1 has a value of $\pi/2$ when $k-4\pi^2\nu^2=0$ and ν has the value of ν_1, the resonant frequency of the system without damping. To the two modes of vibration of the stick will correspond the phase factors β_1 and β_2, and the undamped resonant frequencies ν_1 and ν_2. Plotting β_1 and β_2 against frequency, we have the curves shown in Fig. 4, ν_1 corresponding to the vibrations in the x-direction and β_1 being associated with that mode of vibration. ν_3 is the frequency at which the system is driven by the pencil. The fact that ν_3 will vary considerably does not invalidate the principle to be illustrated. An examination of Fig. 4 shows that for all values of ν, β_1 is always greater than β_2. Let the difference between β_1 and β_2 be δ, a quantity that is positive for all values of ν. This quantity δ is the angle by which the x-vibration lags behind the y-vibration. Fig. 5 shows the directions of rotation in the ellipses which correspond to the vibrations set up in (*a*) and (*b*) of Fig. 2. The exact shape of the ellipses depends not only on the relative amplitudes but also on the phase difference δ. The propeller is driven by the friction between the pin and the surface of the hole in the propeller, the latter being several times the diameter of the former. This accounts for the ability of the pin to start the propeller from rest.

The simple form of the apparatus discussed here is capable of being compounded into a more complex arrangement of several propellers. The axes of the vibrating members may be set so that some produce clockwise and others counterclockwise motion, thus providing the interesting demonstration piece shown in Fig. 1*b*.

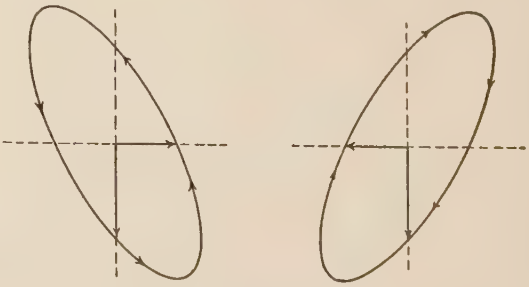

FIG. 5.

A Practical Hearing Aid for Classroom Use

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Department of Physics, Iowa State College, Ames, Iowa

THE student with impaired hearing constitutes no small problem. Being unable to hear much of the classroom discussion, he is forced to rely on what he can see and, since this generally is inadequate, the instructor must frequently supply the discussions in private sessions.

There is no reason why a deaf student should not enjoy the educational opportunities available generally—provided, of course, he is not totally devoid of all hearing ability. The writer was confronted with this problem a year ago when he found that two members of one of his classes could hear only a small part of what was going on. One of these students could hear when his best ear was talked directly into, while the other, along with some lip reading ability, possessed about 25 percent of normal hearing. A makeshift amplifier was quickly assembled to ascertain what decibel gain would be necessary to boost the level enough to make these individuals hear. Both students were, of course, glad to cooperate in these experiments and, as it turned out, the problem proved to be comparatively simple.

Fig. 1 shows the external appearance of the amplifying unit as finally evolved. It is self-contained and a.c. operated. A piezoelectric lapel-type microphone was chosen, mainly because no additional energy supply is necessary to operate it and no impedence-matching trans-. former is needed, even with an input cord 40 to 50 ft. long. Such a long microphone cord allows the instructor almost complete freedom even in a large lecture room. In practice, however, it has been found sufficient to hang the microphone in a central location. If reverberations in the room are not too severe, the amplifier gain is enough to give ample headphone volume. The instrument has provision for four telephone receivers, each of which has its own volume control. The students who use the amplifier see that it is put in operation at the beginning of the class period and afterward put it away in proper shape ready for the next time.

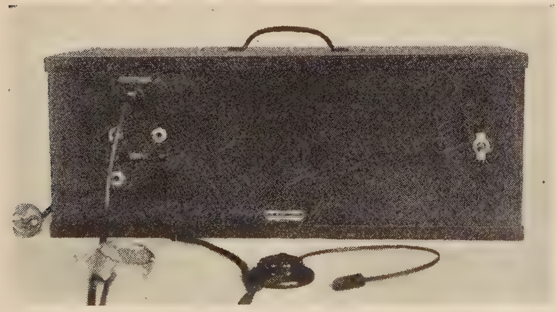

FIG. 1. Photograph of the amplifying unit.

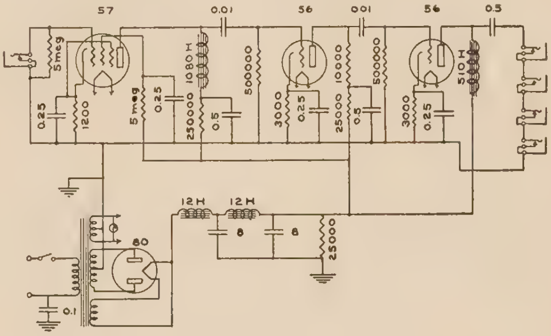

FIG. 2. Diagram of the circuit.

The circuit diagram shown in Fig. 2 is self-explanatory. The high gain type-57 tube is followed by two type-56 tubes. There is nothing critical about the wiring and the whole job can be assembled by a local radio repair man or by student labor. The cost of parts, exclusive of the microphone and earphones, is about $20.00. It is advisable to use high quality parts throughout if uninterrupted service is to be expected.

Five of these units have been in operation here for over a year with complete success. They are checked out at the beginning of each term to those departments in which deaf students are enroled. The instruments are examined periodically to see that they are operating properly, although it appears that, aside from an occasional tube replacement, they are good for indefinite service.

Newton's Rings and Haidinger's Fringes by Reflection from Platinum-Sputtered Surfaces[1]

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Department of Physics, West Virginia University, Morgantown, West Virginia

THIS paper is written at the suggestion of professors of physics visiting our laboratory to whom the writer has shown these interference fringes. Many teachers are familiar with the fringes but it is hoped that some will find here suggestions for variations of the experiments that are more commonly performed. The fringes are more striking in appearance than the photographs show them to be.

Newton's rings

While working with the well-known experiment[2] for finding the radius of curvature of a lens surface by measuring the radii of Newton's rings in reflected light, with a traveling microscope, it occurred to the writer to increase the brightness of the rings by increasing the reflecting powers of the lens and plane-plate surfaces adjacent to the separating air space. When this was done it was found that the appearance of the rings was very much like that of the rings seen in a Fabry and Perot interferometer.

A plano lens (no dioptric power) having radii of curvature of about 42 cm was platinum-sputtered on its convex surface until the reflecting power was judged to be 50 percent. Also a common plate glass 3×3 cm was platinum-sputtered until the coat was nearly opaque. These surfaces have been used repeatedly for several years without renewing the coatings. They do not tarnish, and with reasonable care do not become badly scratched. In the experiment for measuring the radius of curvature of a lens the sharpness and wide separation of the bright rings enable students to obtain excellent results.

The method of platinizing the surfaces was essentially that described by E. O. Hulbert.[3] A small a.c. transformer designed for use with spectrum tubes provided the voltage. The two precautions in sputtering the surfaces were found to be: (1) to remove with ammonia the acids used in cleaning the surfaces; (2) to use shields inside and air blasts outside the bell jar to keep the wax seals from contaminating the sputtered coating.

With the arrangement shown in Fig. 1 the surfaces exhibit sharp rings to the edge of the plate. Measurements can be made with ease and accuracy up to and beyond the 100th ring, and 250 rings can be counted. Fig. 2 is a photograph made when the microscope had been displaced 13.6 mm from the center of the ring system, the distance computed from the known lens-radius for setting the cross-hair (the dark line) on the 1000th ring from the center, for $\lambda = 4358$A; the

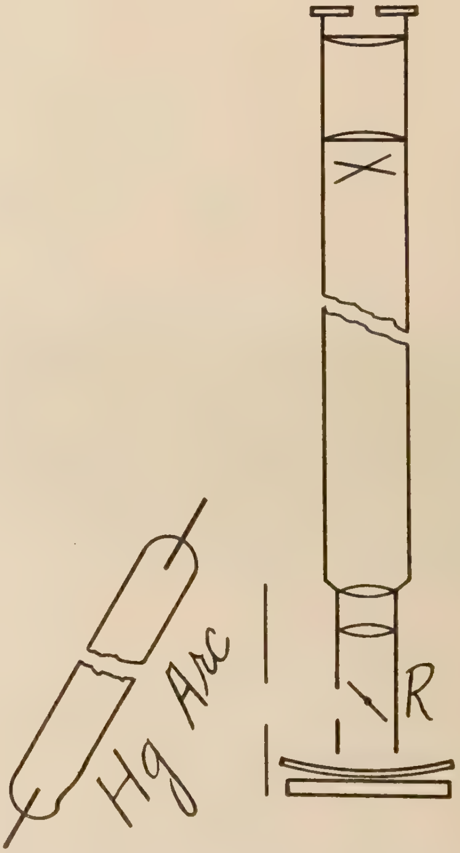

Fig. 1. Microscope and light source. The microscope carries the reflector *R* and travels in a direction normal to the paper.

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[1] Phys. Rev. (Abstract) **49**, 87 (1936).

[2] Robertson, *Introduction to Physical Optics* (ed. 2), p. 208.

[3] R. S. I. **5**, 84 (1934).

FIG. 2. A region around the 1000th ring.

spectrographic camera ($F=20$ in.) used was placed directly above the microscope.

The central part of the system of rings (about 250 rings with $\lambda=4358$A) is shown in Fig. 3. This photograph was made with the lens of a Graflex camera so arranged that it magnified the image of the rings to about seven times the diameter of the actual rings. For visual work $\lambda=5461$A may be used. Observe that the lower order fringes resemble those of Fabry and Perot interferometers, narrow and widely separated.

Haidinger's fringes[4] in reflected light

A plane parallel optical glass plate $30\times30\times3.5$ mm was platinum-sputtered to reflect 50 percent of incident light from one surface, and then was sputtered nearly opaque on the second surface. Using the light from a Cooper Hewitt mercury-in-glass lamp, or that from a sodium arc, one can view Haidinger's fringes merely by facing the light and looking normally at the half-platinized surface, taking care to shield the plate from direct light. The image of one's face is a pattern of bright and dark circles with a dark center at the image of the pupil of the eye. The effect is illusory, for the rings must be at an infinite distance behind the plate, as is evidenced by the accompanying photographs made with cameras focused for parallel light.

In Fig. 4 is seen the aluminum-coated paper, about 3×3 in. in size, with the small hole at its center. This is the camera "eye" in the camera "face" for making the photographs shown in Figs. 5, 6, and 7. Below the camera "face" is a second, horizontal sheet of aluminum-coated paper used to increase the illumination on the lower part of the "face." The platinized plate was placed in a box to shield it from light other than that reflected from the "face," and at about 10 in. distance, directly in front of the lens. Above the box was placed the mercury lamp, in a position to make the light incident on the "face" at an angle of about 45°.

In Figs. 5, 6, and 7, there is lack of symmetry due to failure to place the camera axis coincident with the normal through the center of the plate. Figs. 5 and 6 give a good idea of the appearance of the rings, which one seems to see centered about his eye when facing the mercury light and

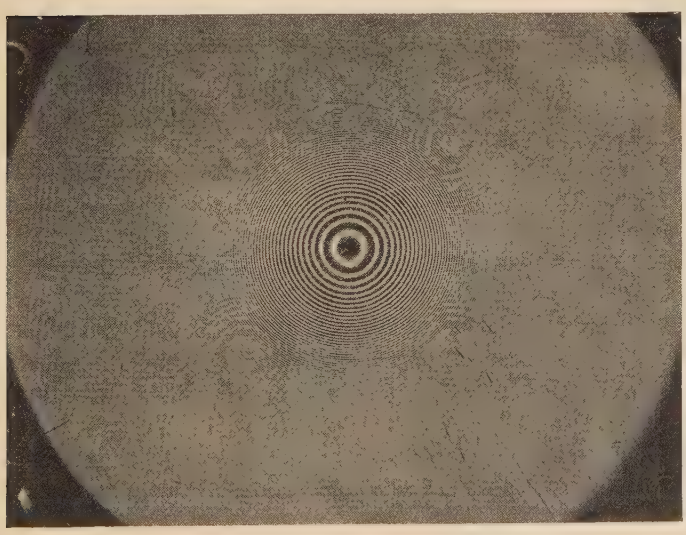

FIG. 3. Central part of the ring system. Examine with a magnifying glass.

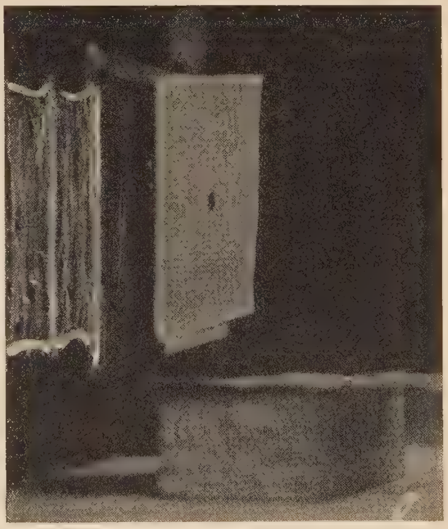

FIG. 4. Apparatus for photographing Haidinger's fringes.

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[4] R. W. Wood, *Physical Optics* (ed. 3), p. 207.

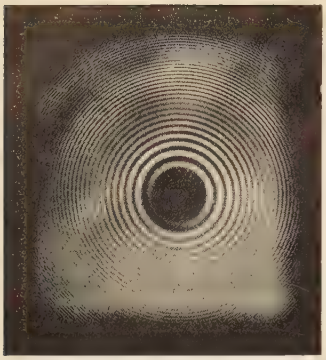

FIG. 5. Photograph of fringes, made with 12-in. component of T.R. lens.

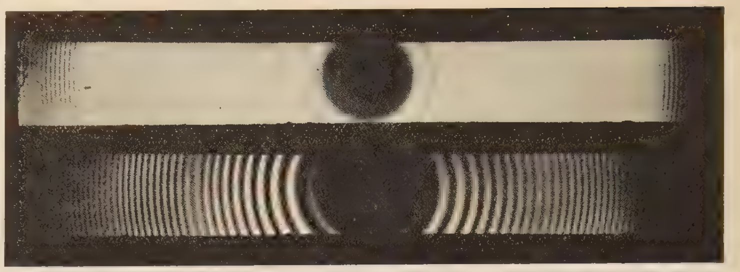

FIG. 7. Two exposures, long and short, of a section of fringes, made with a spectrographic camera.

looking at the plate shielded from direct light. In fact, one can scarcely see an image of his face, for the rings are so prominent. From the theory of the formation of these fringes they must be at an infinite distance behind the plate and not at the distance for which one would look to find an image of his face. As previously mentioned, the camera was in each case focused for parallel light, as it should be for infinitely distant rings.

When this plate is laid upon the table beneath the mercury lamp, parts of the Haidinger's fringes may be seen with the aid of a small telescope even when the inclination of the rays is 65° from normal.

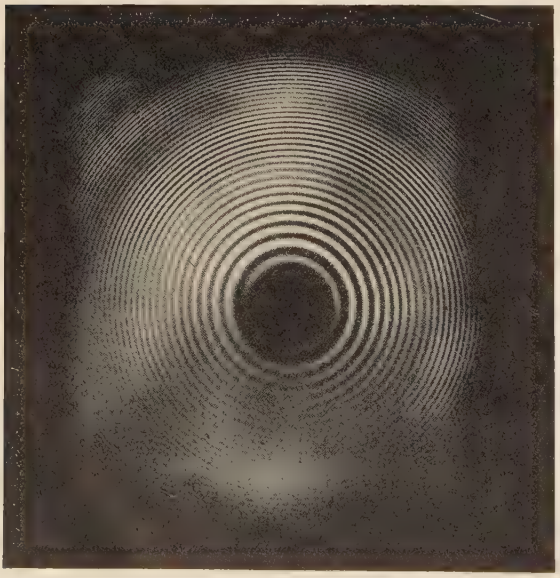

FIG. 6. Same as Fig. 5, but with 18-in. component of T.R. lens.

In some of these photographs the consonance and dissonance between $\lambda = 4358$A and shorter wave-lengths may be seen. The photographs were made by exposing Eastman process plates to the full light of the mercury lamp; $\lambda = 4358$A appears to be the principal line to affect these plates. However, the photograph of Newton's rings (Fig. 3) was made with nearly monochromatic light of wave-length 4358A.

In Wood's *Optics*[4] the suggestion is made that to see the Haidinger's fringes in reflected light, one should reflect the light down upon the plate by means of a clear glass held at an angle of 45°. The writer holds a white card with a small hole in it before the eye and views both equal-inclination and equal-thickness types of fringes in thin plates while facing the mercury lamp and shielding the plate from direct light. This seems to be an easy and a quick way to see the fringes.

The plate to be platinized for the Haidinger's fringes must, of course, be as perfect as the plates of a Michelson interferometer. To protect the coating, the writer fitted the plate into the case of an open-faced watch; the crystal serves as a protecting window and does not impair its use. The plate can then be passed from student to student for observation of the fringes. It should last indefinitely.

The writer is indebted to two former graduate students, Mr. Samuel James Barrett, and Mr. John T. St. Clair, for valuable assistance in sputtering the plates and making photographs of Newton's rings.

A Simple Arrangement for Observation of Electrical Transients

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Department of Physics, Brooklyn College, Brooklyn, New York

If the linear time sweep of a cathode-ray oscillograph is started coincidentally with the application of a transient voltage to the vertically deflecting plates, a momentarily visible trace is formed on the screen. In order to increase the visibility of the trace, some device must be used to start the sweep and transient several times per second, and always in the same relative phase.

As an example of such a device, consider a mechanical contactor; say, a rotating cam. At low sweep speeds this may no doubt produce a satisfactory trace. However, suppose that for satisfactory resolution of the pattern the sweep must be concluded in 1/1000 sec. Then a rotating cam making 30 contacts/sec. will produce a pattern whose brilliance will be approximately 30/1000 of the image brilliance that is possible with the same oscillograph. The other 970/1000 of the electron beam's energy will be concentrated at some point on (or off) the screen. The construction of a device of this type which will make much more frequent contacts would involve vastly increased mechanical labor.

The ideal arrangement should result in the production of one transient for each sweep, with each sweep beginning as soon as the preceding one has ended. A circuit has recently been described[1] that allows the sweep circuit of the oscillograph to "fire" an auxiliary thyratron connected to the transient circuit.

The present arrangement (Fig. 1) takes energy from the sweep circuit itself during the forward sweep and transfers this energy to the transient circuit in time for the next sweep. In Fig. 1, T is the thyratron in the sweep circuit of the oscillograph, and C_2 is the sweep circuit condenser. Aside from the transient circuit $L-C-R$ itself, the only equipment needed is the small capacitance. C_1. The train of events is as follows: (1) During the uniform rise of the sweep voltage, charge passes around C by way of the $L-R$ path, so that C_1 is effectively in parallel with C_2. (2) At the peak of the sweep voltage, T fires and effectively short-circuits C_2; during this instant C_1 is in parallel with C and shares its charge with it. (3) The thyratron deionizes, the next sweep begins, and the oscillating voltage on C is applied to the vertically deflecting plates.

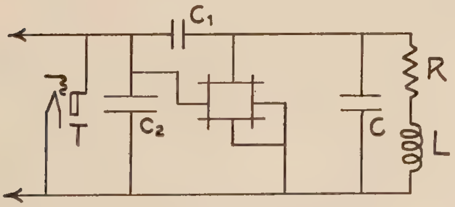

Fig. 1. Diagram of circuit.

The choice of magnitude of C_1 is dependent on the following considerations: (1) The transient voltage peak is determined by C_1, and may be inconveniently small if too small a value of C_1 is chosen. (2) During the sweep, on the other hand, C_1 and C_2 are in series, and the combination is in parallel with C; hence there is superimposed on the rising sweep voltage a transient voltage which, for a given value of C_2, is approximately proportional to C_1. In an extreme case, this voltage has the effect of making the pattern lean over, at least for the large voltage part of the transient. This can be minimized, of course, by making C_1 small compared with C_2.

Analysis of the circuit, applying the appropriate initial conditions, reveals that the only effect of the uniformly rising sweep voltage is to modify very slightly the amplitude of the transient. The effective capacitance in the transient circuit is $C+C_1C_2/(C_1+C_2)$, so that if $C=0$ and C_1 is made small, the resulting pattern shows the decay of voltage in a circuit containing negligible capitance.

If the oscillograph has an amplifier built into it, or if an amplifier is otherwise available, C_1 may conveniently be made quite small, and the transient voltage may be amplified to give the desired deflection. Figs. 2, 3 and 4 were made with one stage of amplification and with $C_1=0.001\mu f$, which was about one hundredth of C_2 or C. The

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[1] H. J. Reich, Elec. Eng. **55**, 1314 (1936).

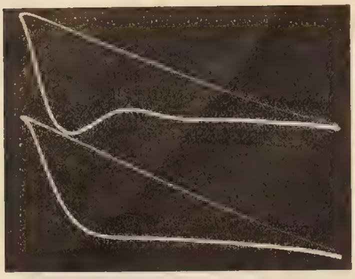

FIG. 2. *Top*, underdamping. *Bottom*, critical damping.

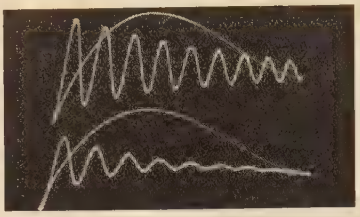

FIG. 3. Patterns with two different values of R.

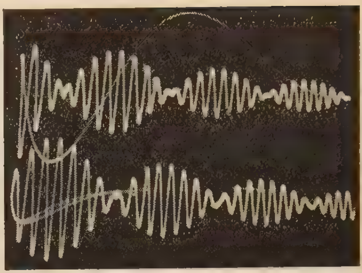

FIG. 4. *Top*, voltage across C of Fig. 5 *Bottom*, voltage across C' of Fig. 5.

patterns thus obtained are as stationary as any locked-in pattern. The frequency of the transient oscillations in the photographs was 12,000 cycles/sec. Each photograph consists of two exposures, the position of the pattern on the screen being shifted between exposures by means of a bias on the vertically deflecting plates. Fig. 4 was made with the dotted connection to point A in Fig. 5 for the upper exposure, and to point B for the lower exposure.

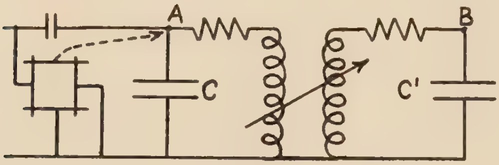

FIG. 5. Arrangement for study of coupled resonating circuits.

Such patterns can be made the basis for a highly instructive laboratory exercise. Frequency may be determined by producing first the locked-in pattern of some known frequency, and then, without disturbing the sweep-frequency adjustments, producing the stationary transient pattern. The frequencies are in the inverse ratio of the respective wave-lengths on the screen. The coefficient of coupling is the reciprocal of the number of waves in one "group" of Fig. 4. The damping factor may also be measured directly. All these quantities may then be compared with those obtained from the known values of L, C, R and M. If C_1 is much smaller than C_2 and C, then both C_1 and C_2 may be omitted from these calculations.

The author wishes to express his thanks to Professor Bernhard Kurrelmeyer of this department for his helpful interest.

Some Simple Experiments on Optical Resolution*

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Department of Physics, University of Arkansas, Fayetteville, Arkansas

SINCE, in common experience, resolution varies directly with magnification, it is difficult for the average student to conceive of these as being separate and distinct quantities. It is, therefore, quite important that the student should see an experiment where resolving power and magnification may be varied independently. While most texts in optics explain the theory of resolving power and how it depends upon diffraction, simple experimental demonstrations of these ideas are seldom described. It therefore may be useful to call attention to a few simple experiments which have been used with marked success by the author.

The simplest type of demonstration can be made by viewing ordinary window screen through holes of various size (0.5 to 4 mm in diameter) in cardboard or metal. The window screen should be well illuminated and 5 to 8 ft. away. The cardboard should be held close to the eye. As the screen is viewed through holes of increasing size, the resolution becomes better, but of course the magnification remains the same.

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*Paper No. 467; Journal Series, University of Arkansas.

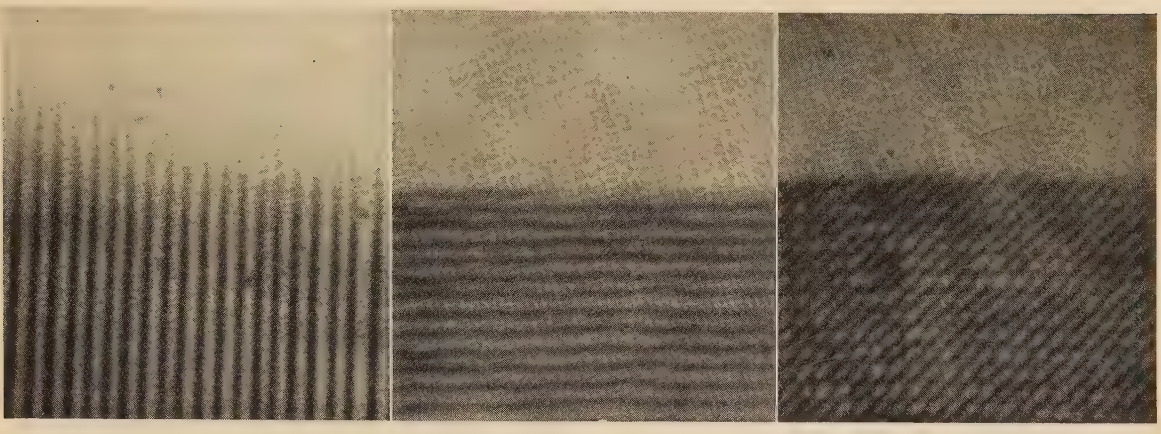

(a) (b) (c)

FIG. 1. (*a*) The magnified image of the edge of a 200-mesh screen when a slit is placed in front of the objective lens of the telescope and parallel to the horizontal edge of the screen. (*b*) In this case the slit was rotated into a position at right angles to the horizontal edge of the screen. (*c*) Appearance of the image when the slit makes an angle of 45° with the wires, and 90° with the apparent lines of the image.

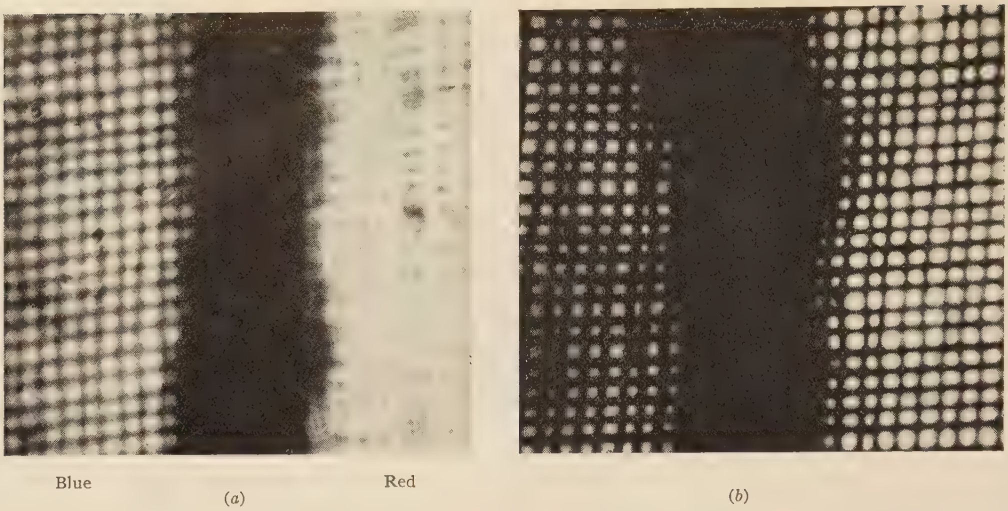
If the cardboard with holes is replaced by one with a thin slit, a striking phenomenon is observed. If the slit is horizontal, only the vertical wires of the screen can be seen. If the slit is turned into a vertical position, only the horizontal wires will be visible. This of course is due to the fact that a slit has a larger resolving power in one particular direction than in any other. Thus if the slit is horizontal, points close together in a horizontal plane will be seen as distinct points while points lying the same distance apart in any other plane will not be resolved; hence the vertical lines will appear distinct while the horizontal lines will be invisible (Fig. 1*a*).

If the slit is turned so as to make an angle of 45° with the wires of the screen, a pattern of wires can be seen running through the screen at an angle of 90° with the slit. While this pattern is not very distinct when viewed with the naked eye, it can be made quite plain with a telescope system (Fig. 1*c*).

All of these experiments may be elaborated for use in the optics laboratory with the help of a telescope system. The objective lens of the telescope should best be a photographic lens with iris diaphragm although a good galvanometer telescope will do if caps having aperatures of various sizes are provided for the objective lens. A low power microscope may be used for an eyepiece. It would be advantageous if the magnifying power of the microscope could be varied easily.

Again the object to be viewed should be a screen, the size depending somewhat upon the focal length of the objective lens of the "telescope" and upon the distance between lens and screen. For Figs. 1 and 2 an objective lens of focal length 3 in. was used with a 200-mesh screen placed at a distance of 30 in. However, on another occasion, a lens of 10-in. focal length was used with a 15-mesh screen placed about 15 ft. away.

The screen is illuminated with a photoflood bulb whose brightness was controlled by a "Variac." The light is placed a few inches behind the screen. A cap with a slit may be placed over the objective lens of the telescope and the appearance of the image noted as the slit is rotated. A photomicrographic camera may be mounted behind the microscope and photographs made such as those shown in Figs. 1 and 2. A deep red filter (6300–7000A) and a deep blue filter (4500–4800A) were set side by side between the light and the screen, and the screen is viewed through a small aperature. There is a marked difference in resolution between the red and the blue portions of the screen which of course shows the dependency of resolving power upon the wavelength (Fig. 2*a*).



(a) (b)

FIG. 2. Appearance of the image when the left and right sides of the screen are illuminated with blue and red light, respectively. In (a) the numerical aperture of the objective lens was about 0.04; in (b), about 0.8. Note that the film was more sensitive to red than to blue light.

With a given aperture of objective lens the magnifying power can be varied by changing objectives in the microscope; and it is easily seen that although the image is increased in size, its resolution is unchanged.

The author has been quite successful in photographing these phenomena on color film for use in the projection lantern.

A Method for Determining the Ratio of the Effective and the Maximum Voltages of an a.c. Generator

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Department of Physics, Dickinson College, Carlisle, Pennsylvania

THE relation between the effective and the maximum e.m.f.'s of an a.c. generator can easily be shown by diagrams, and the value obtained graphically, or by the calculus on the assumption that the wave form is a sine curve. The following is a simple and direct method for obtaining the result experimentally.

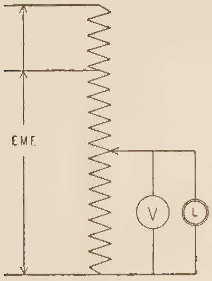

FIG. 1. Wiring diagram.

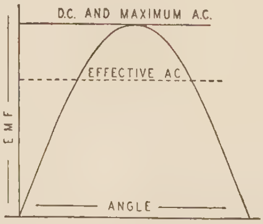

FIG. 2. Showing the voltages involved.

The principal part of the apparatus is a small neon or argon filled lamp which operates on the regular lighting circuit. It is quite generally known that these lamps are very critical as to their minimum starting or striking potential. Using the potentiometer arrangement of Fig. 1, and a 110-v d.c. source, one sets the potentiometer so that the voltage is definitely below the starting potential of the lamp. By slowly increasing the potential drop across the lamp, a point is reached where the lamp suddenly starts to glow. This starting potential V_1 is recorded. The polarity of the source is reversed, and the procedure repeated, the average of V_1 and V_2 being taken as the d.c. starting potential V_d. In the same way, the starting potential V_a of the lamp for a 110-v a.c. source is found. It is to be noted that the readings must be taken when the glow begins, and not when it stops.

From Fig. 2 it is clear that when the d.c. source was used, the lamp responded to the maximum voltage, which was the same as that recorded by the voltmeter. When the a.c. source was used, the lamp responded to the maximum voltage of the a.c. source, which was the same as the constant d.c. voltage. The voltmeter, however, records the effective voltage of an a.c. source. Hence, by dividing the a.c. reading by the average d.c. reading, we obtain the ratio of the effective and maximum voltages of an a.c. generator. Table I shows the results obtained with several lamps.

TABLE I.

	STARTING POTENTIAL				
TYPE OF LAMP	V_1	V_2	V_d	V_a	V_a/V_d
2-w neon	77.5	79.5	78.5	56	0.71
2-w neon	74	73	73.5	52	.71
2-w argon	86.5	85.5	86	61	.71
2-w argon	98	104	101	71	.70
$\frac{1}{2}$-w neon	137	139	138	99	.71
			Correct value		0.707

Teaching Aids

PAMPHLETS AND BROCHURES

Science and the New World (1526-1800). 18 p., 2 plates, 14×21 cm. *Henry E. Huntington Library* (San Marino, Calif.), paper, 10 cts. A description of an exhibition of books to illustrate the scientific contributions and the spread of scientific ideas in America.

Isaac Newton. RUDOLPH E. LANGER. 15 p., 17×25 cm. *Scripta Mathematica* (Yeshiva College, New York), paper, 25 cts. A biographical sketch, reprinted from *Scripta Mathematica*, July, 1936.

Achievements of Civilization. 13×19 cm, paper cover. *Committee on Materials of Instruction, American Council on Education* (5835 Kimbark Ave., Chicago). Five brochures intended to furnish basic informational reading for elementary and secondary school courses, the purpose being to encourage the library method of teaching in schools:

The Story of Numbers, 32 p., 13 fig., 10 cts.
The Story of Weights and Measures, 32 p., 7 fig., 10 cts.
The Story of Our Calendar, 32 p., 6 fig., 10 cts.
Telling Time Through the Centuries, 64 p., 37 fig., 20 cts.
Rules of the Road, 32 p., 12 fig., 10 cts.

Excursions in Science and Engineering. 14 p., 7 fig., 13×20 cm. *General Electric Co.* (Schenectady, N. Y.), gratis. No. 1 of a series of popular "radio talks" which describe researches in progress in the G-E laboratories.

Kelvinator Corporation Publications. *Temperature Research Foundation of Kelvinator Corp.* (420 Lexington Ave., New York), gratis. Four brochures entitled: *An Economist's Appraisal of Domestic Electric Refrigeration; Temperature Control Is Health Insurance, Kitchen Temperatures; Scientific Refrigeration in Relation to Nutrition and Health.*

156 Interesting Experiments in Magnetism and Electricity. 39 p., 101 plates, 21×28 cm. *Educational Electric Mfg. Co.* (Vincennes, Ind.), gratis. A catalog of experiments and demonstrations that can be performed with "Crow's Electrodynamic Equipment."

TRADE PERIODICALS

Shop and Laboratory. *Mico Instrument Co.* (Cambridge, Mass.), gratis. Precision apparatus; notes on shop and laboratory processes and materials.

The Dutch Boy Quarterly. *National Lead Co.* (Room 2020, 111 Broadway, New York), gratis. Practical and technical discussions of paint materials, lead and related products.

Laucks Notebook. *Laucks Laboratories* (314 Maritime Bldg., Seattle, Wash.), gratis. Notes on chemical analysis and testing.

Progress in Pictures. General Electric Co., Educational Sales (Schenectady, N. Y.), gratis. A 4-page rotogravure section containing photographs of scientific and engineering interest.

MOTION PICTURE FILMS

Seeing the Universe. Silent, 16 or 35 mm, 50 min. for 5 reels. *Ruroy Sibley* (410 Cathedral Pkwy., New York), rental or sale. Astronomy films taken at the Mt. Wilson and Yerkes observatories. The five 1-reel subjects are: (1) *The Sun;* (2) *Going to the Moon;* (3) *From Mercury to Mars;* (4) *Jupiter, Saturn and Beyond;* (5) *The Milky Way and the Depths of Space.*

The Construction of Boulder Dam. Silent, 16 or 35 mm, 50 min. *Six Companies, Inc.* (San Francisco), loaned gratis. Story of the building of Boulder Dam, from 1931 to 1937.

DISCUSSION AND CORRESPONDENCE

Proposed Portfolio of Portraits of Eminent Physicists

PLANS are under way for the publication of a portfolio of portraits of eminent physicists, to be published by the journal *Scripta Mathematica* with the editorial assistance of a committee of physicists representing *The American Physics Teacher*. A similar portfolio for mathematics, edited by David Eugene Smith, has already been issued by *Scripta Mathematica.*

The committee for planning the physics portfolio is as follows:

R. T. Birge, *University of California*
Henry Crew, *Northwestern University*
W. F. Magie, *Princeton University*
L. W. Taylor, *Oberlin College*
E. C. Watson, *California Institute of Technology*
J. Ginsburg, Editor of *Scripta Mathematica*
The Editor of *The American Physics Teacher*

In choosing the twelve non-living physicists whose portraits are to be included, the committee makes no pretension of being able to determine the twelve most eminent physicists of all time. An attempt is being made, however, to select physicists who are genuinely great and whose portraits are likely to be of considerable interest to American physicists and students of the science. Account will also have to be taken of the fact that authentic portraits are not available in some cases.

Some fifty names appeared on the initial list considered by the committee. Agreement has been reached on these ten:

Newton
Galileo
Huygens
Ampere
Fresnel
Faraday
Joule
Clausius
Maxwell
Gibbs

The remaining two names will probably be selected from among the following:

Archimedes
Boltzmann
Gilbert
Helmholtz
Hertz
Kelvin
Kirchhoff
Oersted
Rowland

It may be of interest to know that other names considered seriously by one or more members of the committee were: Alhazen, Black, Carnot, Coulomb, Henry, Lorentz, Rayleigh, Roentgen, Rumford, Stevin, Volta, and Young.

The reproductions of the portraits will be approximately 25×35 cm. The present plan is to have each portrait enclosed in a folder containing a biographical sketch of the subject, although another possibility being considered is to have the biographies and portraits bound in a heavy paper cover, but with the latter perforated at the inside margins so as to be removable for framing if desired. It is hoped that the portfolio can be issued early next year. The price will be three dollars, but those who enter their orders in advance of publication, payable upon delivery, will receive a discount of one dollar per portfolio. Orders should be sent to *Scripta Mathematica*, Yeshiva College, New York City.

The committee wishes to acknowledge helpful advice and suggestions concerning the portfolio received from Professors I. S. Bowen, P. Epstein, W. V. Houston, V. F. Lenzen, L. B. Loeb, F. A. Saunders, and R. C. Tolman.

Duane Roller

Violators of Brewster's Law

MANY textbook treatments of Brewster's law fail to recognize the fact that for many specimens of optical glass likely to be at hand in the laboratory this law cannot be even approximately verified.

A simple testing set-up is provided by a student spectrometer with a Polaroid plate or Nicol prism placed before the slit. Since only the roughest sort of monochromatism is required a lamp bulb with red glass filter serves nicely as a light source. The sample under test is mounted on the spectrometer table and the angle of reflection is adjusted for a visual minimum of reflected intensity. The telescope is of no assistance during this adjustment so it is turned aside, but in many instruments it must finally be brought into the line of sight to make the reading of the angle possible.

Recent observations by a student, using reflectors with indexes of refraction ranging from quite low values up to 1.51, showed good agreement between the indexes and the tangents of the angles of polarization; but all dense (high index) flint glass specimens tested showed polarization angles much too small to check with the refraction measurements. One prism with an index of 1.65 showed for the same radiation the polarization angle $\tan^{-1} 1.35$. In another case an index of 1.73 accompanied a tangent of 1.54.

These anomalies were subsequently found to be caused by the chemical tarnish with which flint glasses are known, not to say well known, to be afflicted.[1] Re-grinding and polishing one of the surfaces served to restore completely our faith in Brewster's contention. The tarnish, which possesses a lower index of refraction than the glass, is sufficiently responsible for the surface reflection to have an important effect on the polarizing angle. That the entire observed reflection from these tarnished surfaces does not come from a homogeneous surface layer is indicated, however, by the relatively strong reflection which survives even at the angle of minimum reflected intensity.

Paul Kirkpatrick

Department of Physics,
Stanford University,
California.

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[1] J. Strong, J. O. S. A. **26**, 73 (1936).

The Skidding Automobile

INSTRUCTIONS are occasionally met for bringing an automobile out of a skid, but I do not recall ever seeing a statement as to why the following of the instructions should produce the desired result. A recent article[1] cites the skidding automobile as illustrative of problems in which students may be asked to apply physical principles to new situations; "The student is expected to apply the principle of centrifugal force and indicate the direction in which the wheels should be turned."

Just what approach to the problem the authors had in mind I do not know, and no doubt it may be approached in more than one way. The following discussion does not deal with centrifugal—or centripetal—forces as such, but considers the torque that is needed to change angular momentum.

The principal external forces that act on the car are frictional forces exerted on the wheels by the road. If the clutch is disengaged and the brake released, these forces are nearly perpendicular to the planes of the wheels. If the rear wheels are skidding toward the right the forces on them are toward the left, and if the front wheels are now turned toward the right the external forces on the front wheels are directed toward the right and backward. The resultant torque is in such a sense as to decrease the angular momentum involved in the skid. If the front wheels are turned toward the left the forces acting on the front and rear wheels are more nearly parallel, and any torque they may exert is much smaller. Steering "into the skid" makes the best use of the only external forces that are available for reducing the angular momentum.

ARTHUR TABER JONES

Smith College,
Northampton, Massachusetts.

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[1] Smith, Tyler, and Heil, Am. Phys. Teacher, 5, 106 (1937).

Proceedings of the American Association of Physics Teachers

THE DENVER MEETING, JUNE 24, 1937

THE American Association of Physics Teachers held sessions on Thursday, June 24 in conjunction with the Denver meeting of the American Association for the Advancement of Science. The registration of those in attendance lists 34 members of the Association and 31 nonmembers. The following members registered:

H. A. Barton, American Institute of Physics; H. T. Beaver, Colorado State Preparatory School; J. M. Blair, University of Colorado; L. Bockstahler, Northwestern University; P. E. Boucher, Colorado College; H. L. Dodge, University of Oklahoma; C. A. Foster, State Teachers College, Kearney, Nebraska; G. W. Gardiner, Montana State College; J. O. Hamilton, Kansas State College; P. F. Hammond, University of Wyoming; E. L. Harrington, University of Saskatchewan; T. N. Hatfield, Louisiana State University; M. C. Hylan, University of Colorado; J. C. Jensen, Nebraska Wesleyan University; Paul Kirkpatrick, Stanford University; P. E. Klopsteg, Central Scientific Co.; O. C. Lester, University of Colorado; E. M. Little, University of Montana; V. P. Lubovich, University of Colorado; W. H. Michener, Carnegie Institute of Technology; L. B. Morse, College of the City of New York; W. V. Norris, University of Oregon; R. E. Nyswander, University of Denver; W. B. Pietenpol, University of Colorado; Frank H. Pratt, New Jersey College for Women; R. A. Rogers, Park College; H. O. Russell, Santa Anna, California, Junior College; E. H. Schrieber, State Teachers College, Superior, Wisconsin; J. E. Smith, New Mexico Military Institute; J. C. Stearns, Denver University; Orin Tugman, University of Utah; Glen Warner, Wilson Junior College, Chicago; Carl G. Watson, South Dakota School of Mines; J. W. Woodrow, Iowa State College.

The morning session was devoted to the presentation of 15 contributed papers. Their titles and abstracts will appear in the October issue.

The afternoon session was devoted to a symposium of invited papers on the preparation of physics teachers for secondary school work. Dean Homer L. Dodge of the University of Oklahoma presented the subject from the point of view of a desirable training. He stressed the importance of adjusting the science courses at the secondary level to the needs of the student who must be prepared for life in a modern, democratic society that is being greatly affected by the sciences. Taking a broad view of the problem he considered not merely the training of teachers for the traditional course in secondary school physics, but urged that science courses at the secondary level be made a vital part of the environment of the individual rather than a dry compilation of scientific data.

Dean Dodge pointed out that physicists are particularly loath to accept their responsibility to train teachers and revamp their elementary courses in accordance with the changing purposes of education, and that general physics courses are not popular but exist mainly because they are required. He sketched a tentative program for the training of teachers which would also serve to vitalize the physics courses for everyone. Each department should include at least one staff member who is a gifted teacher and primarily interested in the improvement of teaching; subject-matter departments must give attention to teaching as such. In this connection Dean Dodge proposed the inclusion of a special course that is not primarily a review course in general physics and not primarily a teachers' training course, but one that combines both features. Among the changes that he felt must be made are: (1) to make the laboratory a place for experimenting, not just a place to "do" experiments; (2) to stress the methodology of physics even more than the subject matter so that students become imbued with the scientific attitude; (3) to simplify demonstration apparatus so that principles are made real and understandable; (4) to fill the course with a wealth of illustrative material drawn from the experiences of the students; and (5) to present physics as a live and growing subject that can offer the thrill of adventure to the student as well as to the research worker. As a program for the prospective secondary school physics teacher, Dean Dodge urged a large amount of physics, several courses in chemistry, some work in astronomy and geology, and, in addition, courses in logic, economics, sociology, psychology, and mental hygiene.

Professor W. B. Pietenpol of the University of Colorado presented the training of physics teachers in secondary schools from the point of view of conditions as they exist. He reviewed the work which has been done in investigating the preparation of secondary school teachers. As a result of many surveys made in different parts of the country, several conclusions can be made: (1) that conditions with respect to teaching combinations are chaotic; (2) that a premium should be placed on adequate preparation in one or two reasonably well-related subjects rather than on a smattering of preparation in a number of fields; (3) that administrative officers in the secondary schools can do much to improve conditions by selecting teachers properly prepared in specific fields; (4) that for most of the sciences the typical science preparation of teachers is meager, physics being the lowest reported.

The results of a survey of accredited secondary schools in Colorado were presented in the form of distribution curves and tables. It was pointed out that this survey is representative of investigations which had been made in other states. An appreciable number of secondary school science teachers have had no college training in their specific subject. The training of physics teachers is below that of the other sciences. The modal number of hours of training of physics teachers in accredited Colorado secondary schools is that of one year of college physics. In many states surveys indicate less training. In general it may be concluded that *more than 80 percent of the secondary school physics teachers of the country have not had the equivalent of two years of college training in physics.*

It was suggested that much can be done by our colleges and universities to improve this situation. The most logical approach seems to be through a change in the methods of certification of teachers. It was urged that the Association take steps to encourage an adequate subject-matter requirement for all students who expect to teach physics in secondary schools.

Professor J. C. Stearns of the University of Denver presented the relationship of the Association to the training of secondary school teachers. He recognized two aspects of the problem: (1) we must adequately prepare students to teach secondary school physics; (2) we must see that the students thus prepared are the ones who teach physics. The Association of Physics Teachers is giving the profession of physics teaching the dignified standing it merits. It is doing much to improve teaching by providing ways of sharing teaching aids and problems. The teaching projects presented at national meetings inspire enthusiasm and stir that creative urge which is never dead in a good teacher. This leads to independent work on the part of the teacher which begets independent work in the students. The first essential in producing good teachers of physics in the secondary schools is to have good teachers of physics in the colleges; one cannot study under an inspiring teacher without absorbing some of his good qualities so thoroughly that they are unrecognizable as something acquired from another. We should be proud to belong to the profession of teaching, for one needs that pride in order to be an inspiring teacher.

With reference to the concrete problem before us Professor Stearns proposed the following courses of action: (1) an investigation similar to that described by the preceding speaker should be extended to the various states; as in any problem in a science, one must have all the available facts; (2) an investigation of college placement bureaus should be launched; no teacher should be placed in a secondary school position for which he is not adequately trained. Eventually a cooperative survey and movement embracing all the mathematical-physical sciences should be started, and it should be of such magnitude as to demand the attention of accrediting agencies, school boards, and the newspapers. If we actually believe that these sciences are the bases of our material civilization, that they are basic in the training for rigorous analytical thinking, then there is no alternative; we must not weary either in undoing the mischief of others or in doing well our own task.

W. B. PIETENPOL, *Chairman*

Recent Publications

The Concept of Time. LOUISE ROBINSON HEATH, professor of philosophy and psychology in Hood College. 250 p., 13×19 cm. *Univ. of Chicago Press*, $3. The changing forms of the concept of time are traced from the Greeks up to the present, and an attempt is made to formulate the elements thus revealed into a coherent system. Although emphasis is placed on the changes in the concept resulting from such physical theories as relativity and quantum theory, biological implications of equal importance in determining our ideas of time are not neglected.

Properties of Matter. F. C. CHAMPION, lecturer in physics, University of London, and N. DAVY, senior lecturer in physics, University College, Nottingham. 310 p., 161 fig., 15×22 cm. *Prentice-Hall*, $4.50. The emphasis in this up-to-date text for advanced physics and physical chemistry students is on the physical and experimental points of view. The treatment of topics as exercises in applied mathematics has been particularly avoided. The chapter headings are: Units and dimensions, Acceleration due to gravity, Newton's constant of gravitation, Elasticity, Compressibility of solids and liquids, Seismic waves, Capillarity, Surface films, Kinetic theory of matter, Osmotic pressure, Diffusion, Viscosity, Errors of measurement and methods of measuring h. The plan has been to treat selected topics adequately, rather than to cover a wide field. For example, since the advanced study of kinematics, dynamics, central orbits, and gyroscopic motion can be pursued profitably only from the mathematical standpoint, the authors have omitted these subjects from the book. References to source-literature are given. There are numerous problems, with answers and hints for solution.

Physics In Industry. 304 p., 62 fig., 2 tables, 13×19 cm. *American Institute of Physics*, $1.50. This well-planned and very attractively printed book contains the papers presented at the two symposiums on physics in industry held by the member societies of the American Institute of Physics on October 29–31, 1936 in New York. The book deserves wide circulation, for it has the worthy purpose of encouraging the applications of various branches of physics in industry, and doubtless also will prove to be a reference volume of value and interest to those concerned with vocational guidance and with the training of physicists for industrial positions.

There is a Foreword by K. T. Compton and then the ten symposium papers, presented in separate chapters as follows: *Accomplishments of the industrial physicist in the glass industry*, E. C. Sullivan; *Physics in the metal industry*, Z. Jeffries and E. Q. Adams; *Let the physicist change your oil!* P. D. Foote; *Vibration in industry*, J. P. Den Hartog; *Building—the forgotten child of industry*, J. E. Burchard; *The evolution of the crystal wave filter*, O. E. Buckley; *The physicist gets air minded*, C. B. Millikan; *Some physical problems in the electrical power industry*, J. Slepian; *Training physicists for industry, from the point of view of the educator*, H. L. Dodge; *Training of physicists for industry, from the point of view of the employer*, A. R. Olpin.

It is hoped that the American Institute of Physics will continue to sponsor joint meetings of its member societies, and that the result will be a series of books on major problems of professional and scientific interest similar to the present one. Borderline fields such as biophysics, geophysics, and physics in general education need early attention, particularly if the professional problem obviously involved in each of these fields is to be met before it is too late. If experience shows that it is necessary to convince many industries that they will prosper financially by carrying on physical research, is it not reasonable to suppose that we will also have to help educational administrators and the public to see that the individual and society will prosper intellectually and culturally from competent and wise instruction in the science of physics? This is admittedly a problem of primary concern to the American Association of Physics Teachers. Yet it is one in which every physicist should be vitally interested, for it has profound social and professional significance, the latter because it involves the employment of literally thousands of teachers with a basic training in physics. It is for these and similar reasons that we hope that the member societies of the American Institute of Physics will cooperate in sponsoring other symposiums and publications of the same general character as *Physics In Industry*, and that the title for one of the books in the proposed series can appropriately be *Physics in General Education*.—D. R.

Senior Science. G. L. Bush, T. W. Ptacek and J. Kovats, Jr., Science Department, John Adams High School, Cleveland. 835 p., 22×15 cm. *American Book Co.*, $2.20. Special comment on this textbook seems warranted because it illustrates so well both the advantages and the dangers of the current trend toward socialized science instruction on the secondary level. The book "cuts boldly across subject matter lines, stresses applications rather than theory, and directs special attention to . . . social implications." It is intended "not . . . to replace physics and chemistry" but for senior high school students who "would not have taken [these subjects] anyway."

A main argument and a valid one for socialized science instruction is that the non-science major does not progress far enough under the conventional treatment to enable him to recognize the interplay of scientific principles in personal, social, and economic life; science instruction has tended to remain a closed area of learned content. Another argument is the supposed difficulty of teaching science concepts. While need exists for a revision, there is an obvious danger in carrying it too far. The attempt to achieve teachability may result in the omission of everything that requires student effort. Social implications may be so stressed that a so-called "science" course contains very little science, and offers few of the unique educational values of the sciences.

The authors have covered an enormous range of interesting and useful information; they do not seem to have neglected any common experience in which scientific principles are of importance—air conditioning, safety, the weather, textiles, building, . . . The candid treatments of highly-advertised materials such as patent medicines are to be commended. Lengthy instructions are given for such things as good driving, the purchase of electrical appliances, the causes of automobile motor troubles and the best use of refrigerators. The style is chatty and the numerous photographs and figures are well chosen. An unusual feature is the page-length "side-lights" at the end of each chapter which include anecdotes and cursory treatments of scientific concepts.

The compilation of this material has evidently required much time and effort. Unfortunately, emphasis on the social and the practical has been carried so far as to endanger the science presentation. Accuracy of definition and quantitative application of fundamental principles (often even their statement) are missing. Marconi is mentioned but not Maxwell, Sir Malcolm Campbell but not Newton, Elias Howe but not Huygens. The only discussion of the refraction of light is given in a half page, and neither index of refraction nor focal length is mentioned. The language is often needlessly loose. There are definite errors of fact and concept; a painful example is:

> "About halfway around the curve the centrifugal force begins to push the car over into the wrong lane or off the road entirely. This centrifugal force exerted by the momentum of the car is much greater with a high truck than it is with a passenger car because of the lower center of gravity of the latter. The laws of momentum react strongly against making a curve because the momentum tends to keep the car going straight ahead. When one tries to go around a curve, this momentum works against the turning and becomes what is known as the centrifugal force which tends to tip the car over . . . ."

Because of the wealth of practical information which it contains, this book doubtless should be in the reference libraries of secondary schools. If used as a text in a science course, it certainly should be supplemented with considerable science content.—S. M. Skinner, *Columbia University*.

Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

12. Ph.D. Cornell, B.S. Bowdoin College. Age 38, married. 11 yr. teaching in both men's and women's colleges in East and South. Research in electron physics. Special interest in development of demonstration lectures, laboratory experiments and equipment. Glass blowing.

13. Ph.D. Cornell. Age 31, married, 2 children. 4 yr. college teaching, 5 yr. full-time research in x-rays. Primarily interested in college teaching and research. Hobbies: photography, geology, music.

14. Ph.D. Chicago, B.S. Bradley Polytechnic, with minors in math. and chem. Age 25, married. 4 yr. laboratory and teaching assistant, Chicago. Research, Faraday effect at high frequencies.

15. Ph.D. Iowa State, B.S. in E.E. Minnesota. Age 33, unmarried. 5 yr. sales and research engineer, 4 yr. teaching fellow, physics. Research, effect of gas on metal surfaces used for electron recording, etc. Interested in teaching.

16. Ph.D. Indiana. Age 38, married, 2 children, 6 yr. college teaching. Research in acoustics. Trained for teachers college or university position. Interested in teaching, laboratory development, and research.

17. Man, age 39, married, 1 child, Protestant. Ph.D. Univ. of Pittsburgh. 14 yr. teaching undergraduate physics; 5 yr. asst. prof., important eastern university. Desires professorship in medium sized progressive college; available fall 1937.

18. Ph.D. Penn State. Age 36, married. 11 yr. college teaching experience. Prepared to teach and interested in developing strong courses in advanced mechanics, heat, electricity, and modern physics as well as elementary physics. Desires assistant professorship where there is an opportunity to progress and develop.

19. Man, age 32, married, 1 child. Ph.D. Minnesota. Head of physics dept., junior college, 2 yr.; industrial research, Bell Telephone Laboratories, 1 yr. Has taught both physics and astronomy. Interested in teaching or research in a college or in an industrial laboratory.

20. Ph.D. Univ. of Minnesota; S.B., S.M., M. I. T.; 1 yr. grad. work, Univ. of Iowa. Age 38, married, 2 children, 17 yr. teaching experience in universities, colleges and technical schools, including 10 yr. head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge.

The Pennsylvania Conference of College Physics Teachers

A SERIES of discussions of the question of why physics should be taught in the colleges and secondary schools has been undertaken by the Pennsylvania Conference of College Physics Teachers. The possible "markets" for physics are considered by the conference to be: (1) the training of physicists for industry; (2) the training of physicists for teaching; (3) physics as an essential part of training for the "business of living." The first of the "markets" was taken up at the fall meeting of the conference in 1936.

At the meeting to be held at Pennsylvania State College on October 29–30, 1937 it is planned to devote two sessions to the second "market"—the training of physicists for secondary school and college teaching positions. One session will be a panel discussion, led by Professor T. D. Cope, University of Pennsylvania, and Professor S. R. Powers, Teachers College, Columbia University. Organized discussion will be in charge of Professor W. R. Wright, Swarthmore College, Professor J. C. Johnson, West Chester State Teachers College, Doctor Henry Klonower, Pennsylvania Department of Public Instruction, and Professor A. G. Worthing, University of Pittsburgh. After the dinner on October 29, Professor F. K. Richtmyer, Dean of the Graduate School of Cornell University and President of the American Association of Physics Teachers, will speak on the subject, "Training Physicists for Teaching."

The Pennsylvania Conference of Physics Teachers meets every fall at Pennsylvania State College, which is centrally located and easily accessible from all parts of the State. Meetings are also held in the spring upon invitation from some interested department of physics. The conference has no officers and no dues. The meetings are planned by a Committee on Arrangements whose membership reflects the various types and locations of colleges and universities in the state. Every teacher of physics, including chemical physics and physical chemistry, in the recognized colleges of Pennsylvania is invited to attend and to bring guests. The attendance at the fall meetings exceeds 100; at the spring meetings, 50.

The meeting last spring was held at Lancaster on March 26–27, upon the joint invitation of Franklin and Marshall College, the Lancaster branch of the A. A. A. S., and the Pennsylvania Academy of Science. Two sessions were devoted to 13 contributed papers and 7 invited papers. Four of the invited papers dealt with the borderlines between physics and the other sciences; another, with reminiscences of Professor W. S. Franklin, for many years professor of physics in Lehigh University and the first recipient of the A. A. P. T. Award for Notable Contributions to the Teaching of Physics.

The present chairman of the Conference committee on arrangements is Professor Wheeler P. Davey, State College, Pennsylvania.

Digest of Periodical Literature

Lantern Slides for Illustrating Lectures. W. E. FORSYTHE; *Collecting Net* **11**, 1–6, Aug., 1936. There is probably no better method for showing extensive results of experimental work to an audience or for illustrating a lecture than the use of lantern slides. But if slides are used, they should be made visible to the entire audience and should be made so that they show just what they are intended to show. The same rule should hold here as in any other portion of the lecture; that is, hold the interest of the audience and annoy it as little as possible. This paper points out some violations of this rule, observed at recent meetings.

The lecturer should not have to call to the operator when he wants a slide changed or the room lights turned on, for it is a simple matter to signal by means of a lamp or buzzer operated by a switch in the hand of the lecturer. There should also be available, without the lecturer having to ask for it, a pointer of appropriate length.

Sometimes the operator has trouble with his light source. To have to change the carbons or the lamp during a lecture is usually inexcusable. The operator often does not seem to know how to make the various adjustments on the lantern. At a recent meeting the audience was amused and the lecturer annoyed because each slide was slowly destroyed during its projection by being overheated. At one Chemical Society sectional meeting the projected pictures were out of shape and one corner was badly blurred; this was found to be due to poor alignment of the projection lens and the rest of the lantern, and required a pair of pliers to loosen a screw before the lens could be brought into proper adjustment.

At one meeting of the Physical Society the electric line leading into the room was so small that it was impossible to get enough power to operate the light source properly. Several papers had to be presented without slides while a proper power supply was being arranged. The same thing occurred at a meeting of the Illuminating Engineering Society, where, also, the windows were improperly screened. It should be determined in advance what electrical supply is needed and how much outside light can be permitted. If a large lantern is to be used, a special line should be provided so that 10–15 amp. can be delivered without seriously changing the voltage supply.

The size of the projected picture is important. Its width should be 1/10–1/12 of the distance to the part of the audience farthest from the screen. Sometimes a lecturer has prepared slides for projection on a screen 8 ft. wide and finds that only a small machine and a 4-ft. screen are available; this occurred at a recent Physical Society meeting.

The screen should be perpendicular to the line of projection. In a room that has a high stage and the projection instrument located on the floor of the room, the angle between the screen and the line of projection may be such that not only is the picture thrown out of shape but all parts of it cannot be gotten into focus at the same time. If the screen is so low that those in the back of the room cannot see all of the picture, it should be raised and then tilted to bring it into proper position with respect to the line of projection. Sometimes a screen has become so black with dust that much of the light is lost. A screen with an aluminum surface is satisfactory in a long narrow room where no one is obliged to view it from a wide angle, but it reflects light predominantly in the direction of the projector and its brightness diminishes rapidly as it is viewed more and more obliquely. A screen with a white diffusing surface, on the other hand, is approximately of equal brightness as viewed from all angles and is universally satisfactory if the projection lantern is powerful enough. The screen should be hung in such a manner that it will not move, otherwise some part of the picture at times will be out of focus.

The room should not be too dark. Powerful projectors are available at a moderate price and most slides, particularly line-drawings and tabular matter, can be projected in a moderately illuminated room. A bright area on a screen surrounded by darkness is trying on the eyes. Moreover, when the room is dark the speaker cannot be clearly seen. It should be remembered that language consists not only of words but of shrugs, gestures, and facial expressions. In the dark the speaker does not have full control of the audience; the effect is too much like that of a phonograph record. If the light of the room is too strong and the wiring is not divided into circuits so that the front part of the room can be darkened, one or two portable lamps are a help. If the lecturer has considerable to say between slides, it is a good practice to turn on the lights for these intervals.

One should not remove a slide and subject the audience to the glare of the highly illuminated screen. Several methods are used to avoid this. Some slide-holding mechanisms are so made that the new slide can be pushed into one side of the machine and the old one removed simultaneously from the other side. In other types one motion of a lever pushes the new slide in and the return motion removes the old slide. The best method of changing slides, of course, is to use two projection machines with some means of changing from one to the other. This may be done in several ways: by having an iris diaphragm before each projection lens so connected that a movement of a lever opens one of them and closes the other; by lighting one lamp and turning off the other by means of a double-throw switch; by having the resistance in the lamp circuit so connected that one lamp is dimmed as the other is brightened. The last two methods obviously require the use of incandescent lamps. Sometimes two separate lanterns are used to project two pictures at the same time; for example, a picture of an apparatus and the experimental results obtained with it. This is especially effective where the results depend upon some changing conditions of the experiment.

Moving pictures are being used more and more to show results of research. This method of showing data is particularly good if changing conditions are to be reported. Again one should make sure that the operator knows his business; at a recent meeting the audience was kept waiting while the operator worked out the method of operation.

For good pictures good slides must of course be provided. Some slides are so poorly made that the operator has difficulty in getting them in and out of the slide-holder. At a recent meeting several of the slides for one paper were so made that the projected picture was turned through an angle of 90°; this is inexcusable, for the position of use of slides is well standardized. A broken slide can be excused, although it is something to be excused, but there is no excuse for soiled and dirty slides. Finger-marks are particularly objectionable and are sometimes the fault of the operator.

It is almost a universal practice to make slides up as positives. Negative slides have advantages in some cases but they often break due to excessive heating and they generally appear unnatural. Sometimes a lecturer will ask the operator to hold a copy of some plate in the lantern so as to project it on the screen; this is a difficult thing to do and is unnecessary, for it is easy to build up a slide with the help of mats and thin glass plates.

One should study the illustrations and tables that appear in good technical books. Skilled printers have had long experience and have studied these matters; even casual observations of their work by anyone preparing slides will insure improvement.

Most slides are about $3\frac{1}{4}\times 4$ in. However, it is well to confine the illustration to no more than two-thirds this height and width. This will insure against some of the illustration being eclipsed by part of the projection apparatus and in the case of the cheaper projectors will insure against too much distortion. Slides should not contain too much material. Letters properly typed with an ordinary typewriter and photographed make a good appearance when projected. One way to make the copy is to use a good black ribbon and white paper, and to back the paper with a black carbon paper turned with the carbon side toward the sheet so that the typed letters on the front of the paper are backed by the carbon impression. Since original typewriting often lacks blackness and breadth of lines, a good carbon copy may be better than the original. An excellent carbon copy can be made on a heavy sheet of white paper upon which is superimposed a carbon sheet and a thin sheet of paper; with the typewriter ribbon removed, the type hits the thin paper and makes the carbon copy on the heavy sheet. An additional refinement is to use two sheets of thin paper; a carbon sheet is placed in contact with the lower side of the second sheet in addition to the usual carbon paper placed in contact on the upper side. Since this carbon copy has carbon imprint on both sides, the letters are opaque and any irregularities in the blackness of the upper carbon copy are reduced by the black letters on the back; high contrast and perfection of letters are thus obtained. This is an excellent way to make tables from which slides are to be photographed.

For projection in an ordinary lecture room onto a screen 8–10 ft. wide, a line of print across the slide should contain about 50 letters. Larger letters are seldom necessary and smaller ones give projected images that are hard to read. One should never show a line containing more than 70 letters. Lettering for photographic reproduction should be rather heavy; thin lines are often lost. The maximum dimensions of a letter should be at least 1/50 of the maximum dimensions of the drawing from which the slide is to be made. The use of a lettering guide (Wood-Regan Instrument Co., 154 Nassau St., New York, N. Y.) enables even an inexperienced person to do excellent lettering at a fairly rapid rate; the legibility is usually much greater than the best typewritten copy and letters of various sizes can be made, thus making it possible to balance the typography of the slide and to emphasize certain details. Unless one is skilful he should not attempt free-hand lettering. To letter or to draw a picture directly on the slide is unsatisfactory. Ordinary handwriting should never be used.

One often wishes to project a faint spectral line or some image that is faint on the original photograph. No matter how difficult it was for the experimenter to find the image on the original photograph, it should be made so evident on the slide that one will not have to say, "The line is right here but those in the back of the room probably cannot see it." There are methods known to those skilled in the art of making slides for bringing out images that showed poorly on the original plate; a poor slide can also be faked. No one will judge the value of a piece of research by what he sees on the slide; he is more apt to judge it by what he does not see.

Slides should have titles whenever possible. When curves are shown, coordinate lines should be drawn for the main divisions at least. It is better not to photograph ordinary cross section paper but to use paper on which only the main division lines show. The curves should be drawn somewhat heavier than the cross section lines. The scale for each axis and the numerical value of each coordinate line should be indicated. In general, letters larger than those for the standard 50-letter sentence should be used here. Lettering ordinarily should be horizontal except for the designation of the vertical coordinate; sometimes, however, it is better to have the lettering run along a dividing line or curve. Too many curves and too much lettering should be avoided; better use another slide if more than one or two curves are to be shown unless the curves form a closely related family.

It is rarely worth while to show photographs of an entire experimental set-up. The audience is interested in the final results and the special arrangements and precautions that were needed to produce them. Extensive tables of data should also be avoided; few people read them because they are not interested so much in the particular values as in their general trend. If the rule as to the size of the letters were adhered to, many of the objections to tables of data would be removed because it would be impossible to show too much on one slide.

Shading or toning certain areas often adds to the clearness of a chart. This is usually accomplished by the tedious process of cross hatching with results that are far from neat unless the work is done by a capable draftsman. It is better to use a transfer process for the shading of drawings; a wide variety of transfer patterns may be obtained from the Paratone Company, Inc., 416 Plymouth Court, Chicago, Ill.

Lantern slide emulsions are purposely contrasty and fine-grained; these usually go together in emulsions. Contrasty slides are excellent for tabular matter and line-drawings, but not for halftones; slides of interiors, of apparatus, or of lighting effects are commonly unsatisfactory because of the high contrast and short range of shades. If one of the less contrasty emulsions is to be used for making the positive, the plate must of course be cut down to $3\frac{1}{4}\times 4$ in. Panchromatic plates obviously should be used in making the negative of colored originals if the relative brightnesses are to be reproduced satisfactorily.

The American Society of Mechanical Engineers, 29 W. Thirty-ninth Street, New York, has published a pamphlet (1932) on *Engineering and Scientific Charts for Lantern Slides* which contains excellent suggestions for the design of charts for slides.

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